Seward Park Rehabilitation Study:
Juvenile Salmonid Use of Shoreline Habitats in Seward Park, King County, Washington

Fiscal Year 2000
Planning Assistance to the States Report

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EXECUTIVE SUMMARY

The City of Seattle Parks Department owns and maintains Seward Park, located in King County along the Bailey Peninsula in southwestern Lake Washington. Throughout the years in response to erosion the City developed bank protection structures on various portions of the shoreline. Erosion primarily occurs at the park in the form of wave action induced from heavy boat traffic or wind. In many cases it appears that the bank protection methods used have reduced shoreline vegetation and nearshore habitat for fish and wildlife. The City is now interested in rehabilitating the shoreline in many locations in the park to provide more reliable bank protection while enhancing the habitat available to fish and wildlife. In order to achieve this goal the City of Seattle began a Planning Assistance to the States (PAS) study with the US Army Corps of Engineers (Corps) under Section 22 Program of the 1974 Water Resources Development Act in the fall of 1999.

The overall purpose of the Seward Park Rehabilitation Study was to identify potential areas and conceptual rehabilitation techniques that could be used along the shoreline of Seward Park to provide enhanced habitat for juvenile and adult salmonids. Therefore an engineering alaysis of existing bathymetry, direction of wave approach and beach profiles was conducted in an effort to help identify potential rehabilitation areas. Littoral zone fish community interactions and the effects of shoreline modification are poorly understood throughout the country. This is especially the case in the Lake Washington system. Consequently a year long field study was also conducted to address this information gap.. Beach seine and snorkel field surveys were used to determine monthly changes in diel distribution and abundance of salmon fry, overyearlings, and potential predators and their use of various bank features in the nearshore area of Seward Park. These surveys found the highest use of shoreline by juvenile salmonids to have occurred along sections of shoreline that contained overhead cover, complex substrate, shallow-sloping bank and nearshore contours, and banks without armoring. A spawning survey was also conducted in the fall to identify any potential beach spawning by salmonids. Only one redd was found; however the presence of adult sockeye carcasses on the beach throughout October, November, and December indicates that some deepwater spawning may be occurring along the Bailey Peninsula.

Based on the engineering analysis and the information gained from the field surveys, the Corps recommended three statgies for future rehabilitation of Seward Park shoreline:

a) rehabilitating the nearshore area by placing a layer of sand, gravel, and cobbles over the selected portions of the shoreline that are now covered with angular rock. Also, small woody debris would be placed at a number of locations to create additional shoreline complexity.

b) re-vegetating areas in and immediately above the existing bank along the west and north shorelines.

c) creating a shallow nearshore area by excavating upland material along a 500-foot-long section of the southeast shoreline and by allowing natural erosion processes to shape a portion of the adjacent shoreline.

1. INTRODUCTION

The City of Seattle Parks Department (the City) owns and maintains Seward Park, located in King County along the Bailey Peninsula in southwestern Lake Washington. Throughout the years, the City developed bank protection structures on various portions of the shoreline in response to bank erosion. Erosion primarily occurs at the park in the form of wave action induced from heavy boat traffic or wind. Protection measures placed at Seward Park include a variety of small-scale bank protection and beach nourishment projects (e.g., small riprap, concrete, ornamental concrete walls, sand, gravel) and were intended to decrease the frequency and magnitude of shoreline erosion. In many cases, it appears that the aforementioned bank protection methods have reduced shoreline vegetation and nearshore habitat for fish and wildlife. The City is now interested in rehabilitating the shoreline in many locations along Seward Park to provide more reliable bank protection, while enhancing the habitat available to fish and wildlife.

In the fall of 1999 the US Army Corps of Engineers (Corps) began the Seward Park Rehabilitation study with the City under Section 22 Program of the 1974 Water Resources Development Act. The Planning Assistance to States (PAS) Program, (a.k.a. Section 22 Program) is designed to provide Corps expertise to state agencies, cities, counties, and tribes for the development, utilization, and conservation of water and related land resources under a cost-share agreement (50% local and 50% federal).

Since the late 1800's, salmonids have witnessed a dramatic decline in abundance and geographic distribution. These losses are often attributed to the loss of aquatic habitat throughout their native range (Nehlsen et al. 1991). Lake Washington Watershed contains one of the most densely populated metropolitan areas in the Pacific Northwest, which has increased by more than 20 percent since 1980. Chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus confluentus*) were both listed as threatened under the Endangered Species Act over the past several years (64 FR 14308; 64 FR 58910). The decline in the quantity and quality of habitat available was listed as a major factor affecting the continued existence for both species and all life stages within the Puget Sound Evolutionarily Significant Unit (chinook) and Distinct Population Unit (bull trout). In addition to chinook salmon and bull trout, Lake Washington sockeye (*O. nerka*) provide for one of the most popular sport fisheries in the Pacific Northwest. The aforementioned species, as well as other salmonids, may benefit from the provision of bank maintenance projects that are serviceable but yet provide additional littoral areas in Lake Washington that may be utilized by both juvenile and adult salmonids.

The Seward Park Rehabilitation Project was initiated to identify potential areas along the shoreline of Seward Park that could be rehabilitated to provide habitat to juvenile and adult salmonids. The project has two major components, a literature review and field surveys. The review was conducted on literature pertaining to past fisheries studies performed on Lake Washington in Seward Park and literature pertaining to bank protection projects and its effects on fish utilization. The field surveys were designed to identify the existing nearshore and shoreline habitat and then to formulate bank protection measures that will restore habitat available to salmonids along Seward Park. Specifically, our scope of work identified seven tasks:

- Collect depth and substrate information from nearshore areas;
- Collect vegetation information from shoreline areas;
- Utilize snorkel surveys to identify fish presence and/or utilization in shoreline habitats;
- Utilize beach seine surveys to identify fish presence and/or utilization of nearshore habitats;
- Conduct spawning surveys to identify potential beach utilization by adult salmonids;
- Review literature on previous aquatic studies conducted in the area; and
- Review pertinent published information on the effects of bank protection projects on fish habitat utilization.

The following report details the results of the Seward Park Rehabilitation Project initial findings. The results will be incorporated with other study components to identify shoreline rehabilitation practices that will serve to both protect Seward Park from future erosion and provide habitats suitable for use by salmonids residing in Lake Washington.

2. ENVIRONMENTAL SETTING

2.1 LAKE WASHINGTON

Lake Washington is a large mesotrophic lowland lake forming the eastern boundary of the City of Seattle, King County, Washington. The lake is the second largest natural lake in the state of Washington, with a width of 1.6 to 6.1 km, a length of 3.4 km, at total surface area of 9,495 hectares (at full pool, 6.71 m above MSL) and a mean and maximum depth of 33 m and 67 m, respectively (Wolcott 1973, Bartoo 1977, Brenner et al. 1990, USACE 1992). The Lake Washington shoreline, 146 km at full pool, is more than 78% developed with very few kilometers of shoreline in parks or other semi-natural privately owned areas (Chrzastowski 1981). Lake Washington also suffers from a limited littoral area, approximately 7.8% of the total surface area and 8.7% of the total volume are between 0-5 m depth (mean pool = 6.4 m) (Ajwani 1956).

Lake Washington drains a watershed of 1,579 km^2 (607 mi^2) and has its outlet at the Lake Washington Ship Canal (Figure 1). The Ship Canal is 13 km long and has a minimum depth of 9.1 m (USACE 1992). The Cedar River, the largest (42 - 53% of total inflow) tributary with an average discharge of 19.9 cms (704 cfs), enters at the southern end of Lake Washington. The second largest tributary is the Sammamish River, draining Lake Sammamish to the east and entering at the north end of Lake Washington. Sammamish River inflow (mean = 10.4 cms (367 cfs)), comprises 30% of total inflow to lake Washington (Chrzastowski 1981, Solomon 1994). The average water-residence time in Lake Washington is 2.3 years (Edmondson and Lehman 1981).

Inflowing water from the Cedar River is colder and denser than the surface water of Lake Washington during most of the year and thus, tends to sink upon entry to the lake. Inflow from the river enters the lake, settles to a level between the lake surface and the metalimnion and expands horizontally. The prevailing wind direction is predominantly from the south and southwest during the fall, winter, and spring, gusting up to 112 km hr^{-1} (70 mph), while summer winds are generally light and from the north. The combination of wind and Cedar River inflow creates rotating current that provides an overall movement of surface water to the north (CH2M Hill 1975, Solomon 1994). In winter and spring, unmixed Cedar River water may reach as far north as Madison Park during storm events (Edmondson 1991a).

Prior to 1916, the Black River, located at the southern end of Lake Washington, was the main outlet. The Cedar River discharged into the Black River immediately below the lake, and then flowed into the Duwamish River and into Puget Sound. The Lake Washington Ship Canal was dredged to provide navigation from Lake Washington through Lake Union to Puget Sound. The elevation of Lake Washington was also lowered by approximately 2.7 m (9 ft) to that of Lake Union, subsequently the lake now flows through the Ship Canal instead of the Black River channel. The Cedar River was diverted into Lake Washington to maintain the lake level, whereby increasing lake inflow decreased water residence time of Lake Washington (WRIA 1975, Chrzastowski 1981). The Cedar River is regulated by the operation of Cedar Falls Hydroelectric Project, located downstream from Chester Morse Lake, and the annual diversion of approximately 4.8 cms at Landsburg Dam by the City of Seattle Water Department (Stober and Hamalainen 1979).

The elevation of Lake Washington is controlled by the Corps at the Hiram Chittenden Locks (Locks) by regulated outflow through a spillway and lock facility. Throughout the year, the lake level is allowed to fluctuate between 6.09 m (20 ft MSL) and 6.71 m (22 ft) elevation. The lower level (6.1 m) is maintained during the winter for flood storage, to create a "flood pocket" for excess storm water runoff. Lake refill begins on 15 February (6.1 m), and continues until the lake level reaches 6.66 m (21.85 ft), generally in the first week of May. From the first week of May to 31 July, the lake level fluctuates between 6.66 to 6.71 m. Drafting of the lake begins at the end of July, while the average refill rate is 0.007 m per day. Maximum daily extremes of ± 0.046 m in response to flood control situations occasionally occur throughout the winter (P. McGrane, USACE, *pers. comm*.).

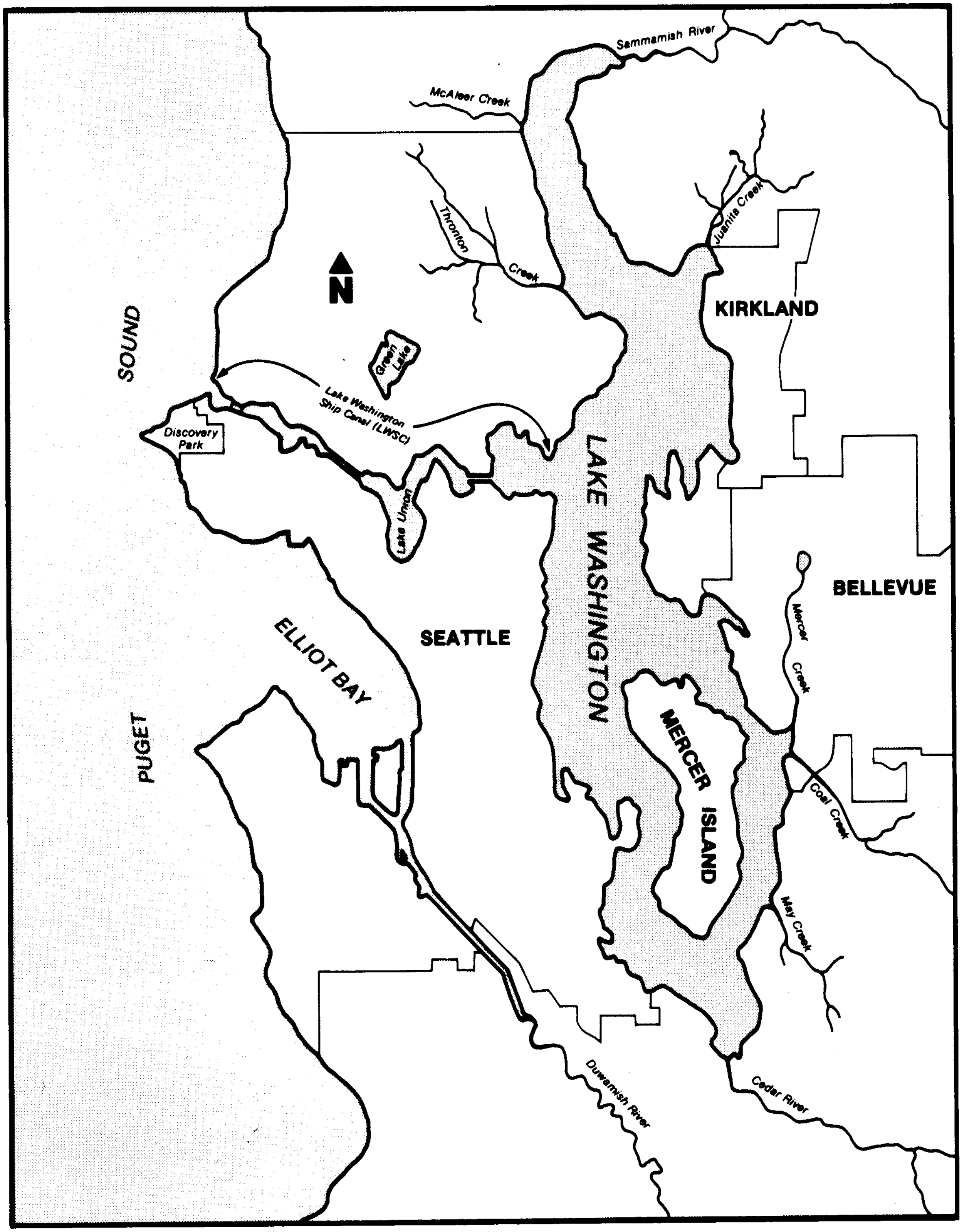


Figure 1. Lake Washington, identifying tributary inflow and outlet to Puget Sound, King County Washington.

2.2 SEWARD PARK

Seward Park is located along the southwest shoreline of Lake Washington, within the limits of the City of Seattle, Washington (Figure 2). The proposed rehabilitation sites are situated on the 200 acre Bailey Peninsula extending from the southwest shore of the lake. (Figure 3). Portions of the Seward Park (Bailey Peninsula) shoreline habitat are composed of medium-sized gravel substrate; however, the banks have been armored in many places with concrete blocks and rock riprap to prevent erosion. Other sections of the shoreline are unarmored and eroding to a moderate degree. Terrestrial vegetation is minimal on the north shore of Seward Park, becoming more dense on the east side. The south shore is armored with a concrete wall (layers of concrete) approximately 0.9 m high (ft) containing solely grass down to waters edge. The wall des not appear to be an effective bank protection measure. The south and east shore of the peninsula are subject to significant wave action from prevailing winds during fall, winter, and spring.

On the north shore, the City constructed a project approximately twenty years ago to nourish the beach with gravel and place two submerged angular-rock berms. This area has not required annual maintenance and has held up well over the years. The outer shoreline along eastern Seward Park is relatively comprised of relatively steep gradient, while the bay inside Seward Park (Andrews Bay) is relatively shallow and well vegetated. Along the north point and the inner shoreline, a gradual shelf extends into Lake Washington for approximately 18-30 m (60-100 ft).

The project area was delineated into six sites during an initial field reconnaissance. These sites are described in detail below:

Site 1

Survey site one is located on the southeast shoreline along the concrete bulkhead section. Except for grass and several scattered cottonwoods (*Populus spp.*), there is little shoreline vegetation. There is no overhanging vegetation present along the shoreline and Eurasian water milfoil (*Myriophyllum spicatum*) and waterweed (*Elodea spp.*) are present about 10 linear m off the shoreline. The substrate is approximately 80% large gravel and 20% cobble. Several large cement blocks are scattered throughout Site 1 (Figure 4).

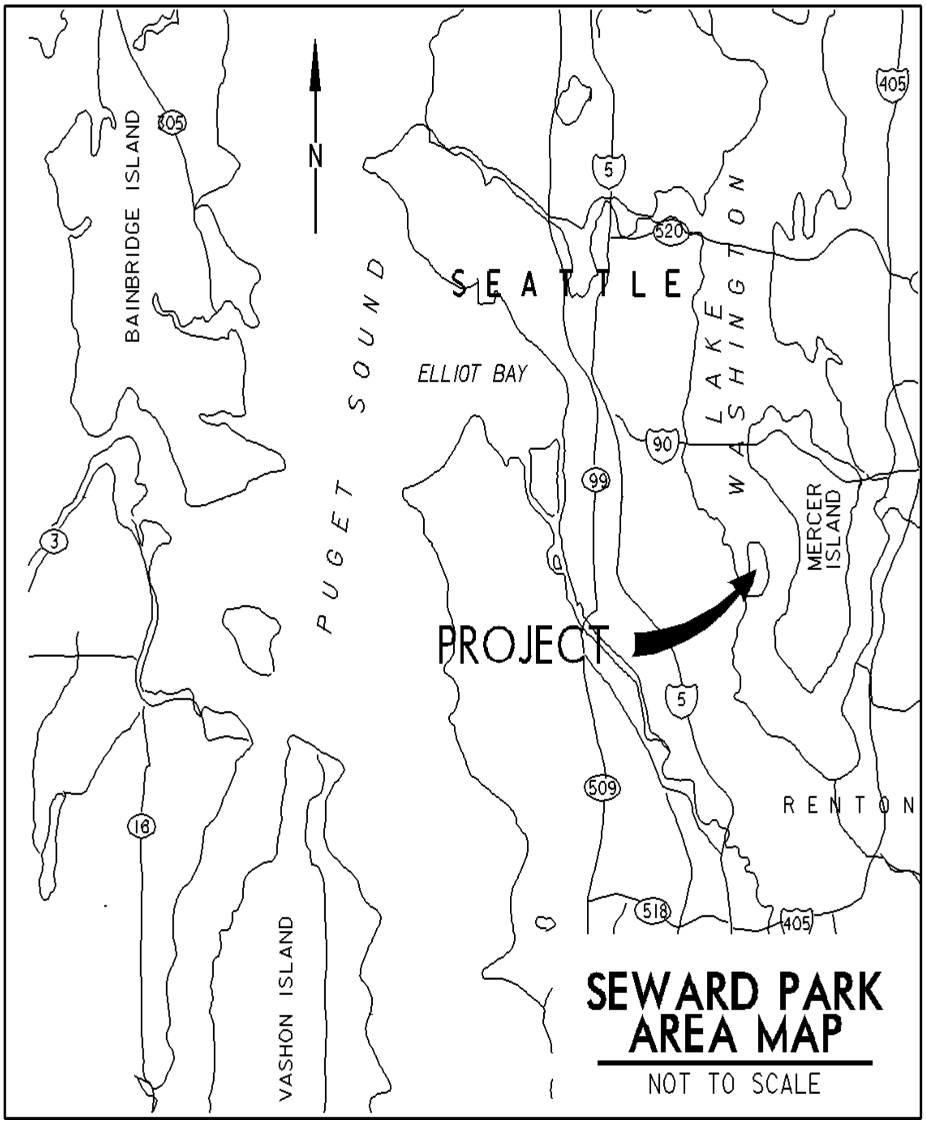


Figure 2. The proposed Seward Park Rehabilitation Site, King County, Washington.

Figure 3. Aerial view of the proposed Rehabilitation project area located at Seward Park, King County, Washington.

Figure 4. Survey Site 1 located along the southeast shoreline of Seward Park, King County, Washington.

Site 2

Survey site 2 is located on the east shore immediately south of the fish hatchery bulkhead (Figure 3). Willows *(Salix spp.*) of about 7-8 m in height line the shoreline along with a single Douglas fir (*Pseudotsuga menziesii*) and cedar tree (*Thuja spp.*). Terrestrial vegetation overhangs waters edge approximately 2-3 m. Milfoil is present approximately 10 m off of the shoreline along with small quantities of waterweed (Figure 5). The substrate is composed of a 50% mixture of gravel and cobble with some sand occurring about 2 m off of the shoreline.

Figure 5. Survey Site 2 located along the east shoreline of Seward Park, King County, Washington.

Site 3

Survey Site 3 is located on the northeast shore of Seward Park. The entire shoreline vegetation consists of mowed grasses and blackberry without overhanging vegetation

(Figure 6). Milfoil is present approximately 10 m off-shore, while the nearshore substrate (up to 3 m off-shore) consists of angular quarry spalls. A 50% mixture of sand and cobble compose the substrate beyond 3 m.

Figure 6. Survey Site 3 located along the northeast shoreline of Seward Park, King County, Washington.

Site 4

The fourth survey site is located on the north beach of Seward Park directly adjacent to the public restrooms (Figure 7). All shoreline vegetation is absent and milfoil is present about 10 m from shoreline. The nearshore substrate is comprised entirely of gravel, while the offshore substrate consists of a 50% cobble and sand mixture.

Figure 7. Survey Site 4 located along the north shoreline of Seward Park, King County, Washington.

Site 5

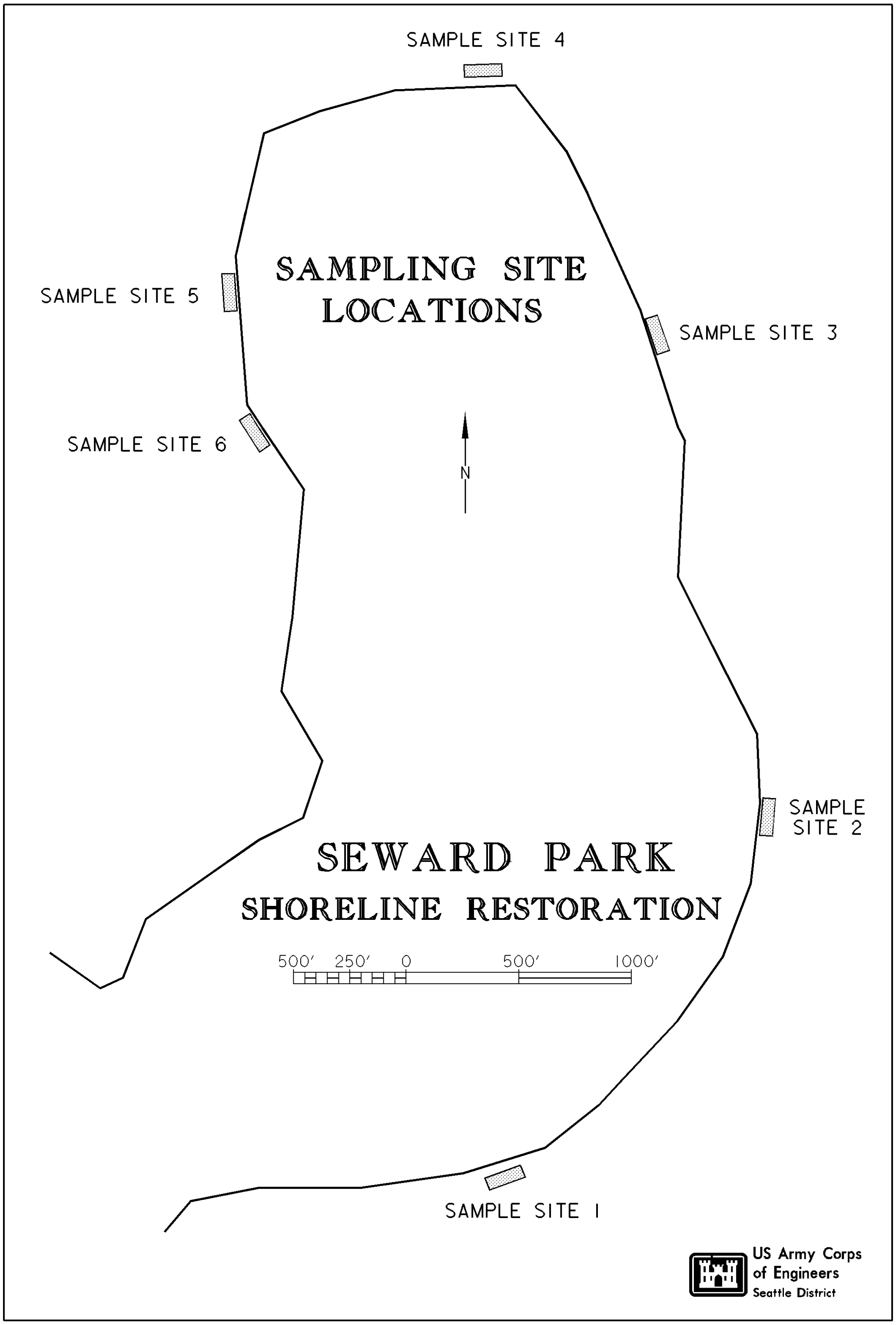
Survey Site 5 is located on the west shoreline of Seward Park, just south of the phone call box and fishing pier. Terrestrial vegetation consists of 95% blackberry (*Rubus spp.*) and 5% willow. There is no overhanging vegetation at this site (Figure 8). Nearshore substrate is comprised of 95% gravel and 5% sand, while the offshore substrate is approximately 60% gravel and 40% sand.

Figure 8. Survey Site 5 located along the west shoreline of Seward Park, King County, Washington.

Site 6

The final survey site, Site 6 is located on the northwest shore of Seward Park. Terrestrial vegetation consists of an even mixture big leaf maple (*Acer macrophyllum*), willow, blackberry, alder (*Alnus spp.*), and snowberry (*Symphoricarpos spp.*). Mature Douglas fir and willows extend 2-3 m over waters edge. Nearshore substrate consists of quarry spalls, while offshore substrate is comprised of a 50% mixture of cobble and sand.

Figure 9. Survey Site 6 located along the west shoreline of Seward Park, King County, Washington.


SAMPLE SITE 4
SAMPLING SITE LOCATIONS
SAMPLE SITE 5
SAMPLE SITE 3
SAMPLE SITE 6
N
SAMPLE SITE 2
SEWARD PARK
SHORELINE RESTORATION
500' 250' 0 500' 1000'
SAMPLE SITE 1
US Army Corps of Engineers
Seattle District

2.3 BIOLOGICAL RESOURCES

Ajwani (1956) reported 20 native and 15 introduced fish species in the Lake Washington watershed (Table 1). Of those species, 14 are considered common or abundant in Lake Washington, including prickly sculpin, longfin smelt, juvenile sockeye salmon, three-spine stickleback (*Gasterosteus aculeatus*), peamouth (*Mylocheilus caurinus*), yellow perch, rainbow trout (*O. mykiss*), northern pikeminnow (*Ptychocheilus oregonensis*), largescale sucker (*Catostomus macrocheilus*), brown bullhead (*Ictalurus nebulosus*), cutthroat trout, smallmouth bass, largemouth bass, and common carp (*Cyprinus carpio*) (Beauchamp 1990).

Table 1. List of fish species present of Lake Washington, King County, Washington (asterisk denotes that fish species is not native to the basin).

Species	***Scientific Name***
Sockeye salmon/kokanee	*Oncorhynchus nerka*
Chinook salmon	*O. tshawytscha*
Coho salmon	*O. kisutch*
Cutthroat trout	*O. clarki*
Steelhead/rainbow trout	*O. mykiss*
Squawfish	*Ptychocheilus oregonensis*
Rocky Mountain whitefish	*Prosopium williamsoni*
Peamouth chub	*Mylocheilus caurinus*
Coastrange sculpin	*Cottus aleuticus*
Prickly sculpin	*C. asper*
Riffle sculpin	*C. gulosus*
Torrent sculpin (Cedar River)	*C. rhotheus*
Three-spine stickleback	*Gasterosteus aculeatus*
Longfin smelt	*Spirinchus taleichthys*
Pacific lamprey	*Entosphenus tridentatus*
Brook lamprey	*Lampetra planeri*
River lampery	*Lampetra fluviatilis*
Redside shiner	*Richardsonius balteatus*
Largemouth bass*	*Micropterus salmoides*
Smallmouth bass*	*Micropterus dolomeiui*
Yellow perch*	*Perca flavescens*
Common carp*	*Cyprinus carpio*
Brown bullhead*	*Ictalurus nebulosus*
Black crappie*	*Pomoxis nigromaculatus*
White crappie*	*Pomoxis annularis*
Bluegill*	*Lepomis macrocheilus*

Tench*	*Tinca tinca*
Atlantic salmon*	*Salmo salar*
Goldfish*	*Carassius auratus*
Pumpkinseed sunfish*	*Lepomis gibbosus*

2.3.1 SPECIES OF CONCERN

In order to analyze the effects of the Seward Park Rehabilitation Project, it is necessary to understand the ecology and biology of fish species, particularly within the project area. This project's primary focus is to benefit salmonids residing in Lake Washington by providing additional littoral habitat. The following review of species life histories will be focused on salmonids present in Lake Washington.

2.3.1.1 Chinook Salmon

Species Description

Chinook salmon are the largest of all Pacific salmon. The chinook salmon is the largest of the seven species of Pacific salmon. Mature adults can reach weights in excess of 40 kg. Chinook are the least numerous of the five Pacific salmon species that occur in North America. Adults are distinguished by the black irregular spotting on the back and dorsal fins and on both lobes of the caudal fin. Chinook salmon also have a black pigment along the gum line, hence the name "blackmouth" in some areas.

In the ocean, chinook salmon are a robust, deep-bodied fish with a bluish-green coloration on the back which fades to a silvery color on the sides and white on the belly. Colors of spawning chinook salmon in fresh water range from red to copper, to almost black, depending on location and degree of maturation. Males are more deeply colored than the females and also are distinguished by their "ridgeback" condition and by their hooked nose or upper jaw. Juveniles in fresh water are recognized by well-developed parr marks which are bisected by the lateral line.

Critical Habitat Description

Proposed critical habitat is includes all marine, estuarine and river reaches accessible to chinook salmon in the Puget Sound ESU. Critical habitat consists of the water, substrate, and adjacent riparian zone of accessible estuarine and riverine reaches, as well as some marine areas. Puget Sound marine areas include South Sound, Hood Canal, and North Sound to the international boundary at the out extent of the straight of Georgia, Haro Strait and the Straits of Juan De Fuca to a straight line extending north from the west end of Freshwater Bay, inclusive. Excluded are areas above specific dams or above longstanding, naturally impassable barriers (i.e., natural waterfalls in existence for at least several hundred years). Major river basins containing spawning and rearing habitat for this ESU comprise over 35,000 km^2 in Washington. The following counties lie partially or wholly with these basins: Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Kittitas, Lewis, Mason, Pierce, San Juan, Skagit, Snohomish, Thurston, and Whatcom.

Life History

Chinook display a broad array of tactics that includes variation in age at seaward migration, variation in length of freshwater, estuarine, and oceanic residence, variation in ocean distribution and ocean migratory patterns, and variation in age and season of spawning migration.

Individual spawning populations of chinook salmon tend to be relatively small, typically not more than a few tens of thousands. Healey (1991) reports that 80% of the chinook populations in British Columbia average fewer than 1,000 spawners. Larger river systems tend to support the largest populations (Healey 1991).

Lake Washington and Cedar River chinook salmon are similar in their adult return and spawn timing in comparison to other southern Puget Sound stocks. Adults are usually first seen at the Locks in mid-June with peak passage in mid- to late August. Passage through the Locks and the Ship Canal are usually complete by late September or early October (F. Goetz, USACE, *pers. comm.*; Myers et al. 1998). The majority of Puget Sound chinook mature as 3- and 4-year-olds, although they may return as early as 2 years of age, or even later than 6 years (Myers et al. 1998). Healey (1991) found that temperature, dissolved oxygen, and weather may influence chinook salmon to hold in the estuary until conditions are correct to continue upstream to spawn. As the largest of the Pacific salmon, adult chinook use mainstem rivers and larger tributaries for spawning. As such, they are found in the largest tributaries to Lake Washington with the majority of production occurring in the Cedar River watershed. During late summer and early fall, they will hold in deep pools in the lower reaches until cooling temperatures and fall rains result in higher baseflows.

Chinook spawning behavior is similar to that of other salmonids. The female selects an appropriate location over gravel and small cobble substrate where she excavates the redd. After spawning, females have been reported to remain on the redd from 4 to 26 days until they die or become too weak to hold in the current (Neilson and Green 1981, Neilson and Banford 1983). During this period, females will vigorously defend the redd against the spawning activity of recently arriving fish. Cedar River chinook begin spawning in mid-September with peak activity in early October continuing through mid-November. The median time of river entry has remained fairly constant (6 October) from 1964-1994 (Warner and Fresh 1999).

After spawning, females guard redds for up to three weeks before dying; males attempt to fertilize other redds before dying (Healey 1991). Chinook spawning within Lake Washington tributaries occurs from early September through mid-December (Myers et al. 1998). The larger body size of the chinook also allows for use of larger spawning gravel and cobble substrates than the other salmonids (Raleigh et al. 1986). Chinook eggs require 882 to 991 temperature units on average before hatching (1 temperature unit = 1 degree C above freezing for 24 h) (Beauchamp et al. 1983). In Puget Sound streams, the length of incubation varies depending on location of redds, but is generally completed by the end of February. The young remain in the gravels for 2 to 3 weeks after hatching (Wydoski and Whitney 1979).

Lake Washington Basin chinook are relatively well-matched with the description for "ocean-type" chinook (Myers et al. 1998). In general, ocean-type fish move relatively rapidly through fresh water into coastal or estuarine rearing areas, compared to their stream-type counterparts (63 FR 11482; Wydoski and Whitney 1979). However, they no longer have access to their historical estuary, the Duwamish River. Chinook, more than most salmon species, have a variety of coping mechanisms that allow adaptation to changing environment, in particular they have a wide-variety of early life-history rearing strategies, reflected by variation in river (or lake) residence time, size at time of migration, and timing of migration. The ocean-type chinook in Lake Washington typically begin their downstream migration as sub-yearlings (Myers et al. 1998). However as a group, fall/summer chinook exhibit many variations in juvenile life history patterns (Healey 1991). Five different juvenile chinook salmon life history strategies are suggested by Reimers (1971):

- Emergent fry move directly downstream and into the estuary within a few weeks;
- Juveniles rear in the main river or remain in tributaries until early summer, emigrating into the estuary for a short rearing period before entering the ocean;
- Juveniles rear in the main river or tributaries until early summer, then emigrate into the estuary for an extended rearing period before entering the ocean in autumn;
- Juveniles rear in the tributary streams, or in the main river, until autumn rainfall begins before they emigrate to the ocean; and
- Juveniles remain in tributary streams, or in the main river, through the summer, rear in the river until the following spring, and enter the ocean as yearlings.

Juvenile chinook from the Cedar River enter Lake Washington over an extended period ranging from January through mid-July (WDFW and USACE unpublished data). However, evidence that most juvenile chinook begin entering the lake in early January and are leaving Lake Washington as smolts by early July, suggests that juvenile chinook in the lake are exhibiting a "ocean" life history (Reimers 1971). Juvenile chinook migration in the Cedar River has at least two distinct nodes. A large percentage (~70%) of juvenile chinook migrate downstream to Lake Washington as fry (40-45 mm FL) in late March and early April. The early downstream migration of newly emerged fry is probably a dispersal mechanism that helps distribute fry among downstream rearing habitats (Lister and Genoe 1970). A second node of fish (~20%) move downstream to

Lake Washington at approximately 80 mm FL in late May and early June (termed 90-day fry) (M. Martz, USACE, *pers. comm.*). Lister and Walker (1966) observed a similar bimodal distribution of chinook fry in the Big Qualicum River, British Columbia. They found that chinook fry migrated either within a short time of their emergence or after six weeks or more of rearing. The early group of fry measured 40-48 mm in length and migrated downstream during late March and April. A later pulse of fry migrated downstream during May and early June and measured 60-90 mm in length. The wide variation in outmigrant size may indicate that some fish are rearing in the river while others are entering and rearing in the lake (Table 2).

Table 2. Mean monthly size (mm FL) of emigrating chinook salmon juveniles captured in the lower Cedar River, Washington, 1998 (adapted from D. Seiler; WDFW; unpublished data).

	Survey Month					
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Size (mm)	40	40	43	61	75	96

Haw and Buckley (1962) reported extended freshwater rearing of juvenile chinook in Lakes Washington and Sammamish, with age-1+, and -2+ smolts representing 21% and 12% of sampled returning adults, respectively. The majority of age-0+ chinook juveniles in the Lake Washington watershed leave the lake by mid-summer; 66% of the returning adults sampled by Haw and Buckley (1962) had been age-0+ smolts. Tabor and Chan (1996) captured two juvenile chinook yearlings (234 and 280 mm FL) in south Lake Washington in March 1995. Although it is not known whether these yearlings reared in the lake or in a tributary, their larger size is typical of lake-rearing fish. The appearance of small numbers of age-1+ and 2+ chinook juveniles in Lake Washington provides additional evidence that extended freshwater rearing is occurring in Lake Washington. Lake Washington chinook are fairly atypical by chinook standards whereby they have an extended period of lake-rearing; the only other known stocks in Washington with possible lake rearing demographics include Lakes Quinault and Ozette. Outside Washington, the Wood River in Alaska has a chain lake system that would indicate a significant amount of lake-rearing potential. Based on historical information, most juvenile chinook migrate through the Locks to Puget Sound later than most other river systems, passing the project from late May through July (Table 3). The beginning and end of the chinook outmigration season appears to vary less than the timing of the peak of downstream migration (Healey 1991).

Table 3. Historical emigration timing of chinook salmon smolts at the Chittenden Locks, Seattle, Washington (source = Woodey 1967; 1969; 1970; Traynor 1971).

	Chinook Salmon					Mean		
	Catch hr^{-1}	**Catch hr^{-1}**	**Catch hr^{-1}**	**Catch hr^{-1}**	**Catch hr^{-1}**	**Weekly**	**Monthly**	**Cumulative**
Date	**1967**	**1969**	**1970**	**1971**	**Mean**			
31-Mar	N/A	0.00	N/A	N/A	0.00	0.0%		0.0%
5-Apr	N/A	0.00	0.00	N/A	0.00	0.0%		0.0%
12-Apr	N/A	0.00	N/A	N/A	0.00	0.0%		0.0%
19-Apr	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%
26-Apr	0.00	0.00	0.00	0.00	0.00	0.0%		0.0%
3-May	0.00	0.00	0.00	0.00	0.00	0.0%		0.0%
10-May	4.00	3.39	2.29	0.00	2.42	3.4%		3.4%
17-May	0.00	1.65	0.86	1.03	0.89	1.2%		4.6%
24-May	0.00	0.43	0.00	0.63	0.27	0.4%	6.3%	5.0%
31-May	1.00	0.52	1.06	1.00	0.90	1.3%		6.3%
7-Jun	6.60	5.33	N/A	0.50	4.14	5.8%		12.1%
14-Jun	3.70	N/A	N/A	11.16	7.43	10.4%		22.5%
21-Jun	2.80	N/A	N/A	1.44	2.12	3.0%	53.0%	25.5%
28-Jun	24.00	N/A	N/A	N/A	24.00	33.7%		59.2%
5-Jul	13.00	N/A	N/A	N/A	13.00	18.3%		77.5%
12-Jul	8.00	N/A	N/A	N/A	8.00	11.2%	40.8%	88.8%
19-Jul	8.00	N/A	N/A	N/A	8.00	11.2%	100.0%	100.0%
Mean	*1.81*	*1.03*	*0.53*	*1.58*	*1.40*			

After entering Lake Washington, early migrants are typically small in size and inhabit the near-shore littoral zones as they approach smolt-size (Martz et al. 1996). Surveys of both the limnetic and littoral zones of Lake Washington have indicated that from early February through late May, young-of-the-year chinook occupy the littoral zone exclusively (Warner and Fresh 1999). Yearling and older chinook (monthly mean FL = 256-323 mm) were captured in littoral gill nets (2-8 m deep) in all regions of Lake Washington from January through October in 1984-1985 (D.Beauchamp, Univ. of Washington, *unpublished data*). They feed primarily on aquatic insects (chironomid pupae) (K. Fresh, WDFW, *pers. comm*) and terrestrial insects (Wydoski and Whitney 1979; Tabor and Chan 1996), while Rondorf et al. (1990) found that in a Columbia River reservoir, the diet of juvenile chinook salmon consisted primarily of zooplankton and terrestrial insects. Juvenile chinook adapt to local prey abundance by modifying their selection of prey items (Rondorf et al. 1990).

Chinook juveniles, predominantly large individuals, begin appearing in limnetic sampling gear in late May and June in Lake Washington (Martz et al. 1996). Increasing utilization of the limnetic zone may be an ontogenetic response, a response to increasing temperatures in the littoral zone, or merely represent the capture of outmigrating smolts. The distribution and residence time of juvenile chinook in Lake Washington may be influenced by temperature. Bjornn and Reiser (1991) reported the preferred temperature for chinook as 12-14^{o}C, and temperatures from 23-25^{o} C could be lethal and were actively avoided.

Recently emerged chinook fry have been shown to tolerate high salinity (Wagner et al. 1969). However, most chinook fry are not fully adapted to osmoregulate in saltwater, as evidenced by their elevated blood chloride levels. It has been speculated that elevated blood chloride levels may have a negative effect on the relative survival of fry. Ocean-type chinook fry may be able to exploit estuarine areas by seeking out lower salinity habitats rather than by physiological change to greater salinity tolerance (Clarke et al 1989). Concurrence with this hypothesis is shown by the fry use of estuary habitats of low salinity (<5 ppt) even with higher quality, high-salinity available. Larger and older chinook fry and fingerlings have greater tolerance to saltwater than smaller, younger fish. Furthermore, growth rate is important; faster growing fish, at any length, showing greater saltwater tolerance than slower growing fish. Once chinook fingerlings have exceeded 55 mm FL, salinity tolerance rapidly increases and even direct transfer to seawater results in high survival (Wagner et al. 1969). Based on physiological studies, ocean-type chinook are usually fully smolted at 65-70 mm FL. At the Locks, the point of physical separation of freshwater Lake Union from saline Puget Sound, larger chinook smolts have historically (1967) and recently (1998) been captured compared to other river basins (1967 mean = 110.2 mm (range = 82-137 mm) and 1998 = 105 mm) (J. Woodey, Univ. of Wash., *unpublished data;* E. Warner, Muckleshoot Tribe, *pers. comm.*).

As in other systems, a number of factors affect the survival of Lake Washington chinook salmon, including loss and degradation of stream habitat resulting from a variety of land and water management practices; predation by native and introduced species in river and lake; injury to juvenile fish exiting the lake via the Locks; droughts; floods; over-harvest; and unfavorable ocean conditions. The highly modified environment at the marine-freshwater interface downstream of the Locks creates an additional puzzle. The environment is much different than the natural estuary that was present at the mouth of the Duwamish River. Numerous sources (as cited in Healy 1991) have reported on the importance of estuarine rearing for juvenile ocean-type chinook salmon. The behavior, growth, and survival of juvenile ocean-type chinook salmon in the ship canal downstream of the Locks has not been well studied. However, it seems clear that this environment provides much less favorable conditions than the original estuary at the mouth of the Duwamish River.

Distribution

In North America, chinook salmon range from the Monterey Bay area of California to the Chukchi Sea area of Alaska. On the Asian coast, chinook salmon occur from the Anadyr River area of Siberia southward to Hokkaido, Japan. Chinook are a highly prized sport fish throughout their range in North America. Chinook salmon is the only species of salmon that has been successfully introduced in the southern hemisphere. Presently, spawning populations of chinook exist from the San Joaquin River, California to the Kotzebue Sound, Alaska (Healey 1991). Naturally reproducing populations have become established in New Zealand from introductions of North American chinook in the early part of the twentieth century (Healey 1991). Summer/fall chinook are present in the Lake Washington basin from the Hiram M. Chittenden Locks up to RM 21.8 on the Cedar River. Natural spawning escapement in the Lake Washington basin has averaged 3,143 from 1983-1991, with Cedar River data going back to 1967 (WDFW et al. 1994).

In Washington, chinook salmon spawn in streams in the Columbia River Basin, Puget Sound, and coastal drainages (Wydoski and Whitney 1979). In the Lake Washington watershed, fall-run chinook salmon migrate through Lake Washington to reach spawning grounds in the Cedar and Sammamish river systems and in other Lake Washington tributaries. Washington Department of Fish and Wildlife (WDFW) hatchery staff allow returning progeny of the Issaquah Hatchery to migrate beyond the hatchery weir when egg-take goals have been achieved. Occasional beach spawning within Lake Washington has been observed (Roberson 1967).

Status

The Puget Sound chinook salmon Evolutionary Significant Unit (ESU), including the populations in the Lake Washington Basin, were proposed for listing as threatened under the federal Endangered Species Act on 9 March 1998 (63 FR 11482). Cedar River chinook salmon, along with 28 other stocks, have been placed into the Puget Sound ESU by NMFS (Myers et al. 1998). The Puget Sound ESU encompasses all chinook populations from the Elwha River on the Olympic Peninsula to the Nooksack River in North Puget Sound and south to the Nisqually River. The five-year mean natural escapement (1992-1996) for the Puget Sound ESU is approximately 27,000 spawners; recent total escapement (natural and hatchery fish) has averaged 71,000 spawners (Myers et al. 1998).

Three stocks of chinook are present in Lake Washington: (1) the Issaquah Creek stock, a composite population (utilizing Green River stock) that is at least partially sustained by production from the Issaquah hatchery; (2) the Cedar River stock, classified as native/wild; and (3) the north Lake Washington tributary stock also classified as native/wild. Lake Washington chinook represent approximately 12% of the natural escapement occurring in the Puget Sound ESU. The WDFW listed the status of chinook in the Cedar River as unknown due to unreliable abundance data (WDFW et al. 1994). Summer/fall chinook of the Cedar River basin are distinguished from other Puget Sound stocks by geographic isolation. The stock is native and all production comes from naturally spawning fish. Genetic analysis has not been conducted to date (WDFW et al. 1994). Recent trends in abundance of Lake Washington chinook have declined since 1991. The Lake Washington chinook stock is now considered to be depressed (City of Seattle 1998).

For the past 7-10 years (1987-1996 returns), each of the three Lake Washington stocks has shown a steep downward trend in adult returns. Annually, decline for each run has been greater than 8% with the Cedar River declining at 10.1% per year (5 year geometric mean of 377 fish), North Lake Washington 16.6% (5 year mean of 145 fish), and Issaquah Creek 8.0%. Over a longer time period, the downward trends have been more variable with the Cedar River declining 2.2% (1964-1996) and North Lake Washington 11.1% per year (1983-1996). Of 23 chinook populations in Puget Sound, Lake Washington was among five populations showing the steepest decline (>5% per year) (Meyers et al. 1998).

All trend analysis conducted by WDFW data or NMFS has focused on adult return years from 1996 and earlier. Recent adult returns from 1997 and 1998 have not been incorporated in trend analysis. These two latest years would incorporate some measure of improvements, possibly attributed to increased smolt survival through the Ship Canal and Locks since 1994. Adult returns (run-size counts at the Locks by Muckleshoot Tribe) for these latest two years have averaged approximately 7,500 fish per year, approaching early 1980’s run-size totals. However, adult returns are predominantly hatchery run fish, although recent returns to Bear Creek indicate there may be improvement for some wild stocks in Lake Washington.

2.3.1.2 Coho Salmon

Species Description

Coho salmon is most often confused with the chinook. Both species have distinct black spots on their back and caudal fins. The coho has spots only on the upper lobe of the caudal fin and white gums on the lower jaw, in contrast to the chinook, which has spots on both lobes of the caudal fin and black gums around the teeth in the lower jaw. The typical size of adult coho salmon in the Lake Washington Basin is between 4 and 7 pounds, although fish as large as 10 pounds have been observed. The largest coho in the state weighed 21 pounds, but in recent years large coho have been rare.

Life History

Like all Pacific salmon, coho are anadromous and return to their natal streams to spawn. Coho salmon have one of the more predictable life histories of all Pacific salmon. Juveniles spend approximately 18 months in freshwater and go to sea after their second spring. After growing to maturity in the ocean, they return to their natal streams after 18 months. Adult coho typically begin returning to Lake Washington through the Ship Canal in late August and continue through to mid November(City of Seattle 1998). Coho salmon exhibit two alternate and less common life histories that vary from this pattern. In many populations, a small percentage of coho (typically males) return to spawn after only one summer in salt water. And in some populations, a significant percentage of juveniles spend an extra year rearing in fresh water (Sandercock 1991).

After entering Lake Washington, most coho will remain in the lake for several weeks if river flows are low. As with chinook, coho require both deep holding cover for resting and sufficient discharge (water depths of 0.2 m) to permit upstream movement (Laufle et al. 1986). When river flows rise with fall rain, coho begin to stage at the mouth of the Cedar River. If flows continue to stay high, coho will move upstream and locate preferred spawning habitat in small tributaries with adequate gravel. Females select a site to spawn and dig the redd, which is approximately 3 m^2 (Bell 1991). Males will compete with other males to court females and fertilize the eggs. After fertilization, the eggs are buried by the female, who will guard the redd until she dies 3-15 days later (Sandercock 1991). Coho spawning takes place in the Cedar River from late October through late February (WDFW et al. 1994). Coho spawn in the upper mainstem reaches below Landsburg and in the many tributaries to the Cedar River.

Incubation periods for coho salmon last from 35 to 101 days (Laufle et al. 1986; Sandercock 1991). After hatching, the young typically spend 3 to 4 weeks (depending depth of burial, percentage of fine sediments, and water temperatures) absorbing the yolk sac in gravels before they emerge in early March to mid-May (McMahon 1983; Laufle et al. 1986; Sandercock 1991).

Juvenile coho salmon rear in freshwater for approximately 15-18 months prior to migrating downstream to the ocean, but may extend their rearing period up to two years (Sandercock 1991). While in fresh water, juveniles utilize all accessible reaches of their natal stream systems for rearing, including lakes, seasonally wetted areas, off-channel ponds, sloughs, swamps, and their tributaries (Skeesick 1970; Cederholm and Scarlett 1981; Hartman and Brown 1987; Swales et al. 1988; Bryant et al. 1996; Pollard et al. 1997). Some physical characteristics of habitat typically selected by coho fry and parr include depths greater than 8 cm, low water velocity, and overhead cover (Shirvell 1990; Bugert et al. 1991; Fransen et al. 1993; Fausch 1993). Newly-emerged fry usually congregate in schools in pools of their natal stream. As juveniles grow, they move into more riffle habitat and aggressively defend their territory, resulting in displacement of excess juveniles to downstream habitats (Lister and Genoe 1970). Aggressive behavior may be an important factor maintaining the numbers of juveniles within the carrying capacity of the stream, and distributing juveniles more widely downstream (Chapman 1966; Sabo 1995). Once territories are established, individuals may rear in selected areas of the stream feeding on drifting benthic organisms and terrestrial insects until the following spring (Hart 1973; Cederholm and Scarlett 1981).

Complex woody debris structures and side channels are important habitat elements for juvenile coho salmon, particularly during the summer low-flow period (Grette and Salo

1986; Hilgert and Jeanes 1999), suggesting that the abundance of juvenile coho is often determined by the combination of space, food, and water temperature (Chapman 1966; Sandercock 1991). Studies at the mouth of the Cedar River have shown that most coho enter Lake Washington in May and June, and are > 100 mm FL (F. Goetz, USACE, *pers. comm.*).

The distribution of juvenile coho salmon in Lake Washington and Lake Sammamish is poorly understood. There are indications that juvenile coho are migrating and feeding along the Lake Washington shoreline (Martz et al. 1996). Gill net surveys in all zones of Lake Washington by indicated that coho juveniles were present during May, June, and July; juvenile coho were captured in all Lake Washington littoral areas except during July and August (D. Beauchamp, Univ. of Washington, *unpublished. data*). Juvenile coho may avoid the high temperatures in the littoral zone during the summer, segregating themselves from shore-based sampling efforts. Diet may also be a factor in the distribution of juvenile coho in lakes. Hamilton et al. (1970) found that large coho juveniles were limnetic, with zooplankton as their primary prey. In Chignik Lake, Alaska, yearling coho fed heavily on newly emerged sockeye salmon fry around shoreline spawning and incubation areas (Ruggerone and Rogers 1992). Coho in the littoral zone of Margaret Lake, Alaska, fed entirely on insects (Cartwright and Beauchamp 1995). Aquatic insects comprised 75% of the diet of coho smolts in south Lake Washington during spring (February-June) 1995, and juvenile fish (15%) was the next largest prey item (Tabor and Chan 1996).

Tabor and Chan (1996) found coho smolts in south Lake Washington from April to early June, with peak abundance occurring in early May. Water temperature affects the distribution of coho salmon in lakes and reservoirs. Bjornn and Reiser (1991) reported the preferred temperature for coho as 12 to 14^{o} C, and that water temperatures from 23 to 25^{o} C could be lethal and were actively avoided by most salmonids. Coho appear to adapt to existence in either the littoral or limnetic zones, exploiting available prey items. Because of this adaptability, water temperature may be the most important determinant of coho distribution in lakes.

There is no clear, regional, pattern for either smolt outmigration timing or smolt size. Coho smolt traits of outmigration timing and size appear to be responses to differences in small-scale habitat availability. Smolts residing in ponds or lakes often have different outmigration timing and are a different size than smolts residing in streams within the same basin (Swales et al. 1988, Irvine and Ward 1989, Nielsen 1994). Peak outmigration timing generally occurs in May, with some runs earlier or later, and with most smolts measuring 90-115 mm FL. Smolts from southwest Washington and the Klamath River Basin (northern California) tend to be relatively large, but this is could be related to influence of hatcheries (Meyers et al. 1998). Large smolt sizes observed in Oregon's Tenmile Lakes were thought to have resulted from a productive lake-rearing environment (McGie 1970). Both smolt outmigration timing and size exhibit considerable interannual variation; mean smolt sizes from a single system can vary by over 15 mm between years (Blankenship et al. 1983; Fraser et al. 1983; Lenzi 1983; 1985; 1987), while peak outmigration timing varies by several weeks to a month (Blankenship and Tivel 1980; Seiler et al. 1981; 1984; Blankenship et al. 1983; Fraser et al. 1983; Lenzi 1983; 1985; 1987).

Lake Washington coho salmon captured at the Locks historically (1967-1971) and recently (1998) appear to migrate later (late May to June) and have been larger than the mean size range for other Pacific Northwest river basins (90-115 mm FL). Outmigrating yearling coho tend to move quickly through the estuary compared to other salmonid species (Emmett et al. 1991). Historically, most juvenile coho migrated out through the Locks and into Puget Sound between mid-May through the end of June (peak catch occurred during the last week of May or first week of June) (Table 4). In 1967, the mean length of coho smolts was 141.4 mm FL (range 116-163 mm, n=19) and in 1998, smolts averaged 120 mm FL (D. Seiler, WDFW, *pers. comm*.).

Distribution

Coho salmon are found along the Pacific Coast from Monterey Bay in central California to Point Hope, Alaska (Wydoski and Whitney 1979). In Washington, coho salmon spawn in streams in the Columbia River Basin, Puget Sound, and coastal drainages (Wydoski and Whitney 1979). In the Lake Washington system, coho salmon stocks have been divided into the Lake Washington/Sammamish Tributary stock and the Cedar River stock (WDFW et al. 1994). Adult coho salmon migrate through Lake Washington to reach spawning grounds in the Cedar and Sammamish river systems, and in small tributaries to the lakes.

Table 4. Historical emigration timing of coho salmon smolts at the Chittenden Locks, Seattle, Washington (source = Woodey 1967; 1969; 1970; Traynor 1971).

			Coho Salmon			Mean		
Date	**Catch hr^{-1} 1967**	**Catch hr^{-1} 1969**	**Catch hr^{-1} 1970**	**Catch hr^{-1} 1971**	**Catch hr^{-1} Mean**	**Weekly**	**Monthly**	**Cumulative**
31-Mar	N/A	0.00	N/A	N/A	0.00	0.0%		0.0%
5-Apr	N/A	0.00	0.00	N/A	0.00	0.0%		0.0%
12-Apr	N/A	0.00	N/A	N/A	0.00	0.0%		0.0%
19-Apr	0.00	0.00	0.00	0.00	0.00	0.0%		0.0%
26-Apr	0.00	0.00	1.00	0.00	0.25	2.5%	2.5%	2.5%
3-May	0.00	0.00	0.00	0.58	0.15	1.5%		4.0%
10-May	1.50	0.00	2.29	0.00	0.95	9.5%		13.5%
17-May	1.00	1.00	0.43	0.68	0.78	7.8%		21.3%
24-May	2.50	2.45	3.60	0.00	2.14	21.5%		42.9%
31-May	3.00	0.52	1.41	0.50	1.36	13.7%	54.0%	56.5%
7-Jun	3.00	0.58	N/A	2.00	1.86	18.7%		75.2%
14-Jun	1.00	N/A	N/A	2.48	1.74	17.5%		92.8%
21-Jun	0.00	N/A	N/A	1.44	0.72	7.2%		100.0%
28-Jun	0.00	N/A	N/A	N/A	0.00	0.0%	43.5%	100.0%
5-Jul	0.00	N/A	N/A	N/A	0.00	0.0%		100.0%
12-Jul	0.00	N/A	N/A	N/A	0.00	0.0%		100.0%
19-Jul	0.00	N/A	N/A	N/A	0.00	0.0%	0.0%	100.0%
Average	*1.20*	*0.41*	*1.09*	*0.77*	*0.76*		*100.0%*	

Status

Puget Sound/Strait of Georgia coho salmon stocks are a candidate species for listing under the Endangered Species Act. A preliminary stock status review considered that "listing is not presently warranted" (NMFS preliminary status review as cited in WDFW 1997a). In 1997, NMFS revised its list of candidate species and kept coho salmon as one of six Pacific salmon species open for future consideration (62 FR 37560). Stock status review of Puget Sound/Strait of Georgia coho salmon considered Lake Washington as two separate stocks, mixed or composite and wild, as healthy and depressed, respectively (Weitkamp et al. 1995). In the status review, NMFS analyzed trends in average Puget Sound run size from 1965 through 1993, and trends in abundance for selected Puget Sound stocks with run size estimated by run reconstruction (Weitkamp et al. 1995). Of the stocks examined, two stocks had significant downward trends, five had significant upward trends, and the remainder had no statistically significant trend. Lake Washington coho had an average run size of 25,310 fish with an annual decline of 2.74%. This annual decline was the highest for any stock that was greater than 10,000 spawners.

The coho population in the Lake Washington watershed is comprised of both natural and hatchery subpopulations. Next to sockeye, coho salmon are the second most abundant anadromous salmonid in the Lake Washington Basin. Coho populations in the basin have undergone significant declines in recent years. Coho escapement peaked at over 30,000 fish in 1970, but declined to less than 2,000 fish in 1992. As a result of the continuation of the downward population trend, coho salmon have been considered depressed in the Lake Washington Basin (King County 1993; Fresh 1994). The desired escapement for Lake Washington is 15,000 fish. Lake Washington escapement levels were achieved in 1979 and appears to have been reached in 1995, 1996 and 1997. Official escapement estimates have not been reported for the three most recent years, however, but coho entering the Lake Washington system exceeded 35,000 fish for those years (1995 = 60,000; 1996 and 1997 = 35,000) (M. Mahovolitch, Muckleshoot Tribe, *pers. comm*.).

Washington Department of Fish and Wildlife provided the Corps with 21 years of data on hatchery returns from several Puget Sound streams (D. Seiler, WDFW, *unpublished data*). Lake Washington coho returns are lower than the other two watersheds (smolt to adult survival = 45.2%) (Table 5). Lake Washington is a highly productive lentic system, producing high quality fish, however. For example, in recent years adult coho salmon captured in Lake Washington averaged 3 lbs more than nearby river systems (Mike Mahovolitch, Muckleshoot Tribe, *pers. comm.*). Furthermore, the average length of coho smolts captured at the Locks is larger than almost all other river basins on the west coast (Weitkamp et al. 1995). The adult returns and index of return are counter to the perceived size of Lake Washington coho that is reflected in smolt and adult size.

Table 5. Hatchery coho salmon adult returns for three Puget Sound watersheds (index = return for Issaquah Creek divided by average of the other two hatchery returns) (source = D. Seiler, WDFW, *unpublished data*).

			Percent Adult Return to Hatchery			
Brood Yr	**Smolt Migration Yr**	**Adult Return Yr**	**Skykomish**	**Issaquah**	**Soos Creek**	**Index**
1975	1977	1978	3.74%	4.12%	5.00%	94.28%
1976	1978	1979	3.55%	1.82%	9.80%	27.27%
1977	1979	1980	7.52%	1.97%	12.60%	19.58%
1978	1980	1981	3.17%	2.18%	6.10%	47.03%
1979	1981	1982	1.43%	6.52%	9.00%	125.02%
1980	1982	1983	3.47%	3.69%	13.40%	43.75%
1981	1983	1984	9.51%	3.13%	10.90%	30.67%
1982	1984	1985	7.22%	4.58%	7.20%	63.52%
1983	1985	1986	13.37%	9.45%	15.70%	65.02%
1984	1986	1987	21.53%	11.06%	11.00%	68.00%
1985	1987	1988	10.78%	8.44%	15.00%	65.48%
1986	1988	1989	11.28%	5.84%	9.00%	57.60%
1987	1989	1990	10.38%	0.89%	21.30%	5.62%
1988	1990	1991	11.19%	1.83%	7.40%	19.69%
1989	1991	1992	9.42%	0.65%	6.20%	8.33%
1990	1992	1993	4.69%	0.15%	4.10%	3.41%
1991	1993	1994	8.31%	0.29%	13.10%	2.71%
1992	1994	1995	9.62%	6.13%	3.80%	91.36%
1993	1995	1996	5.94%	3.91%	4.16%	77.43%
1994	1996	1997	6.49%	1.78%	1.76%	43.05%
1995	1997	1998	1.29%	0.69%	2.23%	39.31%
Average			*7.81%*	*3.78%*	*8.98%*	*47.53%*

A further look at the index returns over shorter periods of time provides some insight into how operational changes at the locks may have influenced coho smolt survival. Given the 45.2% (21 yr mean), there are two periods of distinct change, adult return years 1990-1994 (smolt migration years of 1989-1993), and 1995-1997 (smolt migration in 1994-1996). The first period has an average survival of 7% while the second period is 70%, almost a 1000% percent increase from the first to the second period. The first period was for the last few years before monitoring of smolt passage began at the Locks and before any changes were made to improve smolt survival. The second period includes the first four years when operational and structural changes were made to improve smolt passage. Initial changes in the 1994 smolt migration year were as follows: eliminating "miniflushing" by early June; experimenting with slow "lockages"; and removal of the screen over the saltwater drain. Changes in 1995 and 1996 smolt migration years included: eliminating miniflushing at all times; addition of the smolt slide (mid-May 1995, mid-April 1996). In 1997, a sound-guidance test was conducted and the upper lock chamber was not in operation, only full "lockages" were performed which decreased survival was relative to the earlier years. The three year running average "smooths" the differences among individual years and indicates that trends in increasing or decreasing survival. Again, the period from 1990 to 1994 shows a large, downward trend in smolt survival, while 1995 to 1997 shows a near mirror reflection of that trend with a sharp increase in survival.

2.3.1.3 Sockeye Salmon

Species Description

Adult sockeye salmon lack distinct dark spots on their dorsal and caudal fins. A large number (28-40), long, slender gillrakers on the first gill arch distinguish them from chum salmon, which have 19-26 short, stout gill rakers. Spawning adult sockeye are known for their distinctive green heads and bright red bodies. Size at maturity varies considerably between and within populations of sockeye, with larger fish typically spending additional time at sea. The average weight of sockeye returning to the Cedar River is approximately 5.25 lbs.

Life History

The sockeye salmon run in the Lake Washington system is of significant economic and biological importance, is the largest run of this species in the United States outside of Alaska (Stober and Hamalainen 1979). The run enters Lake Washington through the Locks, whereupon the fish traverse the Ship Canal and enter Lake Washington. Sockeye salmon exhibit the greatest variety of life history patterns of all the Pacific salmon, and characteristically make more use of lacustrine habitat than other salmon species. Life history patterns of sockeye include; non-anadromous landlocked sockeye, lake type sockeye, and river or sea type sockeye (Burgner 1991). The resident landlocked sockeye are called kokanee. Kokanee, mature, spawn and die in freshwater without a period of marine residency (Gustafson et al. 1997). Although small numbers of sockeye in the Lake Washington Basin exhibit the resident life history pattern, the vast majority of the population is anadromous. Unlike any of other species of Pacific salmon, juvenile sockeye rear primarily in freshwater lakes.

Sexual maturity in sockeye salmon ranges from 3-8 years (Gustafson et al. 1997). Burgner (1991) reported adult sockeye as reaching a length of 33 inches and a mean weight between 3.5 and 8 lbs. Sockeye will spend 1-4 years in the ocean before returning to freshwater to spawn. Many adult sockeye make long migrations, requiring higher stored energy reserves; delays in migration, such as those caused by dams or low water levels, can decrease spawning success (Hart 1973).

Adult sockeye salmon begin returning to the Lake Washington watershed through the Locks in late May with a peak migration in early July. By mid- to late August, most sockeye have entered the lake. Once in Lake Washington, sockeye move into deep, cold areas below the thermocline. Adults will spend from 1-4 months in this region of the lake, where they undergo final sexual maturation. During this time, gametes mature and the outward appearance of the fish is dramatically transformed by the onset of secondary sexual characteristics. Most fish will move into tributary streams to spawn during the fall, but a relatively small proportion of the population will spawn over selected beach areas along the eastern shore of Lake Washington and along the northern shoreline of Mercer Island.

The Cedar River supports the largest population of returning sockeye salmon in the Lake Washington basin with significant numbers of fish also spawning in Bear, North, Swamp, and Issaquah creeks. It is estimated that greater than 80% of the run spawns in the lower Cedar River at the southern end of Lake Washington, with the remaining 20% spawning in other tributaries to Lake Washington and the Sammamish River, and in littoral areas of Lake Washington. To supplement natural spawning sockeye salmon in the Lake Washington watershed, the WDFW collects Cedar River broodstock for spawning in their temporary hatchery facility, located downstream from Landsburg Dam (RK 34.8).

In general, there has been an increase in sockeye salmon age at return in Lake Washington over the past 25 years compared to age at return in the 1970's. Although age data for sockeye salmon in Lake Washington show large fluctuations, comparison of data from 1970 to 1994 indicates that in early years, less than 5% of returning sockeye salmon were age 5+; presently, an average of 19.5% are age 5+ (Gustafson et al. 1997). In 1992 and 1993, a larger proportion of sockeye salmon of age 1.1 (3-year-olds) occurred in Big Bear and Cottage Lake creeks than in the Cedar River or Issaquah Creek (Hendry 1995; Hendry and Quinn 1997). However, the survey methods used on the Cedar River may have missed the jacks because of their smaller size or potentially different migration timing. If so, data collected from Bear and Cottage creeks may not characterize the overall sockeye salmon jack composition of Lake Washington stocks.

River-spawning sockeye exhibit great diversity in selection of spawning habitat and river entry timing (Gustafson et al. 1997). Areas containing upwelling, oxygenated water, and gravel substrates are important for spawning (Burgner 1991). Spawning occurs from September through January in the lower Cedar River (WDFW et al. 1994). For a given fish size, sockeye salmon have the highest fecundity and the smallest egg size of any Pacific salmon (Gustafson et al. 1997). Cedar River sockeye females average over 3,600 eggs per adult (Gustafson et al. 1997). Length of sockeye egg incubation is temperature dependent, but is generally longer than for other salmon species (Burgner 1991). This appears occur because of the choice of spawning environment (Burgner 1991). In general, spawning occurs during periods of declining temperatures, incubation occurs at the lowest winter temperatures, and hatching is associated with rising water temperatures in late winter or early spring (Burgner 1991).

After emergence, juvenile sockeye will migrate to nursery lakes for rearing, or in the case of river-type sockeye, utilize river and estuarine habitat for rearing, or migrate directly to the sea (Burgner 1991). Initially, upon emergence, juvenile sockeye exhibit photonegative response, moving primarily at night, which is believed to be an anti-predator adaptation (Burgner 1991). Lake-rearing sockeye juveniles typically spend 1-3 years in lacustrine habitats, before migrating to sea (Burgner 1991). Sockeye that rear in rivers for 1 to 2 years (river-type sockeye) are less common than the lake-type sockeye, and little is known about them. River type sockeye migrating as fry to saltwater, or lower river estuaries in the same year as emergence, are termed "sea-type" sockeye (Gustafson et al. 1997). In recent years a number of underyearling (age 0) sockeye were captured at the Locks (Table 6) which coincidentally is similar to the historic proportion (3.7%) of underyearling sockeye captured at the Locks (Warner 1996).

Table 6. Mean length of yearling (age 1) and underyearling (age 0) smolts from the Lake Washington basin captured at the Chittenden Locks, Seattle, Washington (adapted from Gustafson et al. 1997).

Year	**Age**	**No.**	**Mean FL (mm)**	**Range (mm)**	**Mean Weight (g)**	**Source**
1965	1	245	120	--	16.7	Bryant (1976)
1966	1	24	132	--	--	
1967	1	306	129	--	20.5	
1968	1	76	127	--	19.5	
1969	1	227	124	--	17.1	
1996	0	21	95	86-110	--	Warner (1996)
1996	1	541	133	100-185	--	

Burgner et al. (1969) has indicated that the growth rate of juvenile sockeye salmon is directly correlated to the primary productivity of the lake they reside in. Lake Washington was subjected to numerous nutrient inputs prior to 1960 the result of sewage outfall into the lake. However, since the creation of METRO and completion of sewage treatment facilities in 1966, Seattle's waste has been diverted to Puget Sound, and the waste from the other communities surrounding Lake Washington has also been diverted. Lake Washington is more productive than most sockeye lakes in British Columbia and Alaska, which tend to be oligotrophic. Sockeye reside in Lake Washington for only one year, whereas it is common in other systems for sockeye to rear for two or even three years (Burgner 1991; Edmondson 1991a).

Lake Washington sockeye are among the largest of all sockeye smolts when they enter the marine environment (Eggers 1978). Sockeye in Lake Washington experience quite high growth rates compared to other sockeye lakes in British Columbia and Alaska (Edmondson, 1991a). Woodey (1972) found growth rates in summer to range from 0.05 to 0.38 mm d^{-1} during summer and early fall. Growth decreases during the winter months when zooplankton is less available. Woodey (1972) generally found the growth rate to decrease (0.05 mm d^{-1}) during December and January. He also found mean lengths for the 1966-69 year classes to be in the 60 to 65 mm FL by June, with variation between years and between areas of the lake. In Lake Washington, Martz (1996) found little difference in early season littoral daily growth rates, but the daily growth rate (0.34 mm d^{-1}) increased during April and May. Limnetic areas of Lake Washington supported larger daily growth rates (April-May = 23 mm d^{-1}; May-June = 0.46 mm d^{-1}).

Smolt outmigration to the ocean usually occurs during darkness, beginning in late April and extending through early July (Gustafson et al. 1997). Juvenile sockeye entering the Ship Canal appear to maintain nocturnal behavior, however, when entering the locks, juvenile sockeye become more diurnal in their movements (F. Goetz, USACE, *pers. comm*). The majority of sockeye tend to pass through the Locks by the end of May (Table 7). After leaving the Puget Sound, sockeye move north to the Gulf of Alaska.

Table 7. Historical emigration timing of sockeye salmon smolts at the Chittenden Locks, Seattle, Washington (source = Woodey 1967; 1969; 1970; Traynor 1971).

	Sockeye Salmon	Mean

Date	Catch hr^{-1} 1967	Catch hr^{-1} 1969	Catch hr^{-1} 1970	Catch hr^{-1} 1971	Catch hr^{-1} Mean	Weekly	Monthly	Cumulative
31-Mar	N/A	0.00	N/A	N/A	0.00	0.0%		0.0%
5-Apr	N/A	0.00	0.00	N/A	0.00	0.0%		0.0%
12-Apr	N/A	0.00	N/A	N/A	0.00	0.0%		0.0%
19-Apr	31.50	0.38	0.00	0.00	7.97	8.2%		8.2%
26-Apr	90.00	0.08	12.00	7.55	27.41	28.3%	36.5%	36.5%
3-May	3.50	33.14	3.85	19.88	15.09	15.6%		52.1%
10-May	32.00	3.39	8.78	29.32	18.37	19.0%		71.1%
17-May	1.00	21.17	6.87	27.39	14.11	14.6%		85.7%
24-May	8.20	8.08	7.20	4.22	6.93	7.2%		92.8%
31-May	0.50	4.69	0.00	2.50	1.92	2.0%	58.3%	94.8%
7-Jun	1.00	2.05	N/A	1.00	1.35	1.4%		96.2%
14-Jun	1.00	N/A	N/A	3.31	2.16	2.2%		98.5%
21-Jun	1.00	N/A	N/A	0.00	0.50	0.5%		99.0%
28-Jun	0.00	N/A	N/A	N/A	0.00	0.0%	4.1%	99.0%
5-Jul	1.00	N/A	N/A	N/A	1.00	1.0%		100.0%
12-Jul	0.00	N/A	N/A	N/A	0.00	0.0%		100.0%
19-Jul	0.00	N/A	N/A	N/A	0.00	0.0%	1.0%	100.0%
Average	*16.97*	*6.63*	*4.84*	*9.52*	*7.37*			

Distribution

Sockeye range from the Deschutes and Willamette rivers in Oregon to Kotzebue Sound, Alaska. Historically, accounts of sockeye catches exist for California as far south as the Sacramento River, however, today there are no recognized runs existing in that state (Gustafson et al. 1997). The known distribution of river-type sockeye in Puget Sound include the North and South Fork Nooksack, Skagit, Sauk, North Fork Stillaguamish, Samish, and Green river populations (Gustafson et al. 1997). Cedar River sockeye originated from stock transfers from the Baker River in the 1935 and 1940 (Gustafson et al. 1997). Lake Washington basin sockeye extend from the Locks up to RK 35.1 on the Cedar River. Juvenile sockeye are captured in numerous side channels and lateral habitat in the lower Cedar River (M. Martz, USACE, *pers. comm*).

Status

Sockeye salmon are the third most abundant of the Pacific salmon species (Burgner 1991). As such, commercial catches of sockeye comprised 17% by weight and 14% by number of the total salmon catch in the Pacific Ocean from 1952-1976 (Burgner 1991).

Abundance of sockeye in the Cedar River has declined drastically from peak counts in the mid-1970's (WDFW et al. 1994). Mean sockeye escapement in the Lake Washington basin is 166,500 from 1987-1996 (Fresh and Lucchetti 2000). The escapement goal in the Cedar River (350,000) was last achieved in 2000, and the status of the Cedar River sockeye stock is depressed (WDFW et al. 1994; City of Seattle 1998). The mean spawner return ratio during the last 11 brood years for which full return data is available is 0.79, indicating, on average, for each 100 fish that successfully spawns in the basin, only 79 fish have returned to spawn in the subsequent generation. For the period of record (first year = 1967), the escapement goal has been exceeded four times (not including 2000). Since 1988, the mean run size has been approximately 135,000 fish (WDFW 1997b).

Cedar River sockeye were listed as a non-native wild sockeye stock in Washington by the NMFS and were not included in one of the six Evolutionarily Significant Units (ESU) established in 1997 (Gustafson et al. 1997). However, sockeye stocks present in Bear Creek, a tributary to the Sammamish River, is potentially of native origin (63 FR 11749). The Bear Creek stock is considered by NMFS to be a provisional ESU, although it is not believed to be presently in danger of extinction nor is it likely to become endangered in the foreseeable future if present conditions continue (63 FR 11749). The most recent (1991-1995) five yr mean escapement for this provisional ESU was 11,400 sockeye. Abundance decreased by about 7% per year from 1982-1995 and by about 4% per year between 1986-1995. The WDFW et al. (1994) identified four populations of anadromous sockeye salmon in Puget Sound: one population in the Baker River and three populations that occur in the Lake Washington watershed (Cedar River, Issaquah/Bear Creek, and Lake Washington beach spawners).

2.3.1.4 Bull Trout

Species Description

Bull trout is a western North American char in the family Salmonidae. Bull trout were first described as *Salmo spectabilis* by Girard in 1856 from a specimen collected on the lower Columbia River, and subsequently described under a number of names such as

Salmo confluentus and *Salvelinus malma* (Cavender 1978). Bull trout and Dolly Varden (*Salvelinus malma*) were previously considered a single species (Cavender 1978; Bond 1992). In 1978, bull trout were differentiated from Dolly Varden as a separate species (Cavender 1978). The original work was substantiated by investigations of Haas and McPhail (1991). Although bull trout and Dolly Varden co-occur in several northwestern Washington river drainages, there is little evidence of introgression (Haas and McPhail 1991) and the two species appear to be maintaining distinct genomes (Leary et al. 1993; Williams et al. 1995).

Resident adult bull trout range from 150-300 mm TL (6 to 12 in) and migratory adults commonly exced 600 mm (24 in) or more (Pratt 1985; Goetz 1989). The largest verified bull trout is a 14.6 kilogram (kg) (32 pound) specimen captured in Lake Pend Oreille, Idaho, in 1949 (Simpson and Wallace 1982). No obvious differences occur between sexes, except at spawning time. Spawning males in some anadromous populations have a hooked lower jaw (kype).

Life History

Bull trout are found primarily in colder streams, although individual fish are found in larger river systems throughout the Columbia River basin (Fraley and Shepard 1989; Rieman and McIntyre 1993, 1995; Buchanan and Gregory 1997). Water temperature exceeding 15^{o}C (59^{o}F) is believed to limit bull trout distribution, which may partially explain the patchy distribution within a watershed (Fraley and Shepard 1989; Rieman and McIntyre 1995). Several life history forms of bull trout occur, and all may be present within the same population. Fish exhibiting the resident life history strategy are non-migratory, spending their entire lives within their spawning stream. Freshwater bull trout life history forms include adfluvial, which migrate between lakes and streams; fluvial, which migrate within river systems; and resident, which are non-migratory. The fourth strategy, anadromy, occurs when the fish spawn in fresh water after rearing for some portion of their life in the ocean. Due to differences in productivity between small headwater streams and larger rivers, lakes, and marine environments, resident fish are typically smaller than migratory fish.

Bull trout normally reach sexual maturity in 4-7 years and live as long as 12 years. Repeat and alternate year spawning has been reported, although repeat spawning frequency and post-spawning mortality are not well known (Fraley and Shepard 1989; Pratt 1992; Rieman and McIntyre 1996). Bull trout typically spawn from August to November during periods of decreasing water temperatures; however, migratory bull trout frequently begin spawning migrations as early as April (Ratliff et al. 1996), and have been known to move upstream as far as 250 km (155 miles) to spawning grounds (Fraley and Shepard 1989). Spawning typically does not commence until stream temperatures decrease to 8^{o}C, however, water temperature may range from 4-10^{o}C (39 to 51^{o}F), with redds often constructed in stream reaches fed by springs or near other sources of upwelling groundwater (Goetz 1989; Pratt 1992; Rieman and McIntyre 1996.) In Washington, bull trout spawning activity was most intense at 5-6^{o}C (Wydoski and Whiting 1979) and occurs primarily at night (Heimer 1965; Weaver and White 1985). Beach spawning of native char in Lake Washington and Lake Sammamish is improbable. Confirmed observations of beach spawning bull trout are limited to extreme downwelling conditions in cold, high-elevation lakes (WDFW 1998); water temperatures in Lake Washington and Lake Sammamish are too high for successful incubation.

Depending on water temperature, incubation is normally 100 to 145 days (Pratt 1992), and after hatching, juveniles remain in the substrate. Goetz (1989) suggested optimum water temperatures for egg incubation of 2-4^{o}C (35-39^{o}F). Successful egg incubation requires temperatures less than 5^{o}C (WDFW 1999), with maximum survival between 2-4^{o}C. Emergence times may surpass 200 days, while fine sediment can decrease egg-to-fry survival by impeding the flow of water to the eggs or by physically preventing fry emergence (entombment). Maintaining water flow to the developing eggs is necessary to remove metabolic wastes and deliver dissolved oxygen. Fry normally emerge from early April through May depending upon water temperatures and increasing stream flows (Pratt 1992; Ratliff and Howell 1992).

Juvenile bull trout, particularly young of year (YOY), have very specific habitat requirements. Small bull trout (<100 mm), are primarily bottom-dwellers, occupying positions above, on, or below the stream bottom. Bull trout fry are found in shallow, slow backwater side channels or eddies (Shepard et al. 1984, Elliott 1986). Goetz (1989) suggested optimum water temperatures for rearing of about 7-8^{o}C (44-46^{o}F). Adult bull trout, like their young, are associated with complex forms of cover, including large woody debris, undercut banks, boulders, and pools (Oliver 1979; Fraley and Shepard 1989; Goetz 1989; Hoelscher and Bjornn 1989; Sedell and Everest 1991; Pratt 1992; Rich 1996; Sexauer and James 1997; Watson and Hillman 1997). Jakober (1995) observed bull trout overwintering in deep beaver ponds or pools containing large woody debris in the Bitterroot River drainage, Montana, and suggested that suitable winter habitat may be more restrictive than summer habitat.

Distribution

Bull trout are native to the Pacific northwest and western Canada, historically occurring in major river drainages in the Pacific Northwest from the southern limits in the McCloud River in northern California and the Jarbidge River in Nevada to the headwaters of the Yukon River in Northwest Territories, Canada (Cavender 1978; Bond 1992). To the west, bull trout range includes Puget Sound, various coastal rivers of British Columbia, Canada, and southeast Alaska (Bond 1992). Bull trout are frequently observed throughout tributaries of the Columbia River basin, including its headwaters in Montana and Canada. Bull trout also occur in the Klamath River basin of south central Oregon. East of the Continental Divide, bull trout are found in the headwaters of the Saskatchewan River in Alberta and the MacKenzie River system in Alberta and British Columbia (Cavender 1978).

In Washington, bull trout occur within the Columbia River system, in rivers of Puget Sound, and in coastal rivers from Grays Harbor north. Two subpopulations of bull trout are within the Lake Washington basin: the Chester Morse Reservoir subpopulation and the Issaquah Creek-Sammamish River subpopulation (64 FR 58910; WDFW 1998).

Status

The coastal/Puget Sound bull trout population segment was listed as threatened under the Endangered Species Act of 1973, as amended (64 FR 16397). A 1998 WDFW study reported 80 bull trout/Dolly Varden populations in Washington: 14 (18%) were healthy; two (3%) were in poor condition; six (8%) were critical; and the status of 58 (72%) was unknown. Bull trout are estimated to have occupied approximately 60% of the Columbia River Basin and presently occur in only 45% of the estimated historical range (Quigley and Arbelbide 1997).

In the past 10 years, only two "native char" have been reported in Issaquah Creek and none have been reported in the Sammamish River (64 FR 16397; 1999; WDFW 1998). The USFWS is not certain that the latter subpopulation is "viable." There is no known spawning subpopulation resident in Lake Washington or Lake Sammamish, however, bull trout have been observed in the fish ladder viewing pool at the Locks as recently as 1997 (F. Goetz, USACE, *pers. comm*.) and isolated reports of bull trout captures in or around Lake Washington occur every few years. A larger juvenile bull trout (~250 mm, 3 year old) was caught in the lower Cedar River in July of 1998 (M. Martz, USACE, *pers. comm*.).

The only likely viable bull trout subpopulation in the Lake Washington watershed is the Chester Morse Reservoir subpopulation. However, the Chester Morse Reservoir subpopulation is above an anadromous barrier and is a glacial relic population (WDFW 1998). The population exhibits an adfluvial life history strategy, although residents could exist in the upper watershed (WDFW 1998). Because all life history strategies can arise from the same population, it is possible that some fish emigrate from the Chester Morse Reservoir to exhibit anadromy or to reside in Lake Washington. Water temperatures in the lower Cedar River may be too high to support a fluvial population (WDFW 1998).

2.3.1.5 Steelhead

Species Description

Steelhead, once considered a trout, are now considered a Pacific salmon species. The rainbow trout/steelhead group are then separated from the brook trout, lake trout, and Dolly Varden by the complete absence of teeth at the base of the tongue. Generally, steelhead are more slender and streamlined than resident rainbow. Like rainbow, the coloration on the back is basically blue-green shading to olive with black, regularly spaced spots. The black spots also cover both lobes of the tail. The black coloration fades over the lateral line to a silver white coloration blending more to white on the stomach. Steelhead from the ocean are much more silver than the resident rainbow. On steelhead the typical colors and spots of the trout appear to be coming from beneath a dominant silvery sheen. The silvery sheen gradually fades in fresh water, and steelhead become difficult to differentiate from resident rainbow trout as the spawning period approaches. Steelhead and rainbow lack the red slash characteristic of cutthroat trout, but do have white leading edges on the anal, pectoral, and pelvic fins. Spawning steelhead and rainbow develop a distinct pink to red strip-like coloration that blends along the side, both above and below the lateral line. On steelhead, the rainbow trout coloration gradually fades following spawning to the more characteristic silvery color that the fish display during their ocean journey. The distinct and beautiful coloration of steelhead during the freshwater spawning period is apparently important in regard to the mating and reproductive process. The silvery sheen and streamlined shape of ocean-bright steelhead is essential to survival in the ocean environment.

Life History

Steelhead life history characteristics are quite diverse, exemplifying their extensive ability to adapt to a wide variety of environmental conditions. Steelhead are anadromous fish that home to their natal rivers to spawn. After maturation, steelhead reside in open ocean feeding areas and migrate to their natal streams to spawn. Most (60-75%) of the steelhead originating from Washington streams remain at sea for two years prior to returning to freshwater, the remaining balance spend three years in the ocean (Grette and Salo 1986). Most steelhead populations have a period of freshwater entry that lasts several months and is comprised of many minor peaks in abundance of immigrants. Entry into freshwater can be influenced by tides and stream discharge. However, steelhead do not typically remain in the estuary if stream conditions are favorable for their spawning migration (Shapovalov and Taft 1954; Withler 1966, Everest 1973, Oguss and Evan 1978). Steelhead populations are typically divided into two seasonal races of fish that are primarily defined by the timing of adult returns to spawning streams and by the state of sexual maturity upon entry into fresh water (Neave 1944; Shapovalov and Taft 1954; Bali 1959; Withler 1966; Smith 1968). Stream-maturing steelhead (also called summer steelhead) enter freshwater in an immature life stage, while ocean-maturing (or winter steelhead) enter freshwater with well developed sexual organs (Busby et al. 1996). Summer steelhead return to freshwater between May and October, and winter steelhead return to fresh water between November and April (Withler 1966; Smith 1968). The native Lake Washington steelhead stock are considered a winter-entry race. Entry to the Lake Washington watershed typically occurs between mid-January and the end of May (F. Goetz, USACE, *pers. comm*.).

Summer steelhead usually reside in the freshwater environment for several months before spawning while their winter counterparts spend much less time between freshwater entry and spawning (Shapovalov and Taft 1954, Withler 1966) Summer steelhead also tend to have a higher percentage of body fat than winter steelhead when returning to freshwater (Smith 1968). Despite their significant behavioral and physiological differences, both summer and winter steelhead typically spawn between January and May. Spawn time for steelhead in the Cedar River ranged from early March to mid-June in 1998 (Burton and Little 1998).

In general, steelhead differ from spawning chinook and coho salmon by their use of faster, shallower, and higher gradient locations in mainstem or tributary streams (Everest and Chapman 1972). Caldwell and Hirschey (1989) observed steelhead spawning in the Green River, Washington in velocities ranging from approximately 0.6-0.9 m sec^{-1} (2.0-4.0 fps), and depths ranging from 0.5-1.1 m (1.6-3.7 ft). Caldwell and Hirschey (1989) also report preferred spawning substrate composed of predominantly large gravel, with some small cobble. Pauley et al. (1986) found steelhead spawning in gravel ranging from 1.3-11.4 cm (0.5-4.5 in) in diameter.

One significant difference between steelhead and Pacific salmon life histories is that not all steelhead adults die after spawning. Steelhead are capable of repeat spawning (iteroparous), although the incidence is relatively low and specific to individual streams. Steelhead rarely spawn more than twice before dying, most that do are females (61 FR 41541). Repeat spawning in Washington ranges from 4.4 to 14.0% of total spawning runs (Wydoski and Whitney 1979).

As with other salmonids, incubation rates for steelhead eggs vary with water temperature, with fry emergence occurring 40 to 80 days after spawning. During egg incubation, survival of embryos depends upon the size of gravel in the redd, permeability of the substrate, and amount of intra-gravel flow (Bley and Moring 1988; Chapman et al. 1995). Dissolved oxygen levels at or near saturation with no temporary reductions in concentration below 5 ppm are most suitable for incubation (Stolz and Schnell 1991). The larval fish (alevins) remain in the redd for an additional 3-5 weeks, absorbing nutrients from a yolk sac connected to their abdomen. Steelhead alevins emerge at night and begin feeding within days emergence. Less than 20% of these fry will survive their first year in the stream environment because they are highly vulnerable to predation and extreme winter and spring flow conditions that can cause significant scour and premature outmigration (Seelbach 1987). Emergence studies occurring in the Cedar River in 1996 and 1997 indicate that fry emergence for an individual redd begins approximately 54 days after fertilization and is complete approximately 63 days after fertilization (Burton and Little 1997). In comparison with other river basins, Cedar River steelhead fry had the shortest emergence time of almost all other river basins. Mean number of days to reach the beginning and end of emergence ranged from 52-112 days and 63-132 days, respectively (Burton and Little 1998). The survival rate of steelhead embryos depends on the amount of fine sediments in the redd, predation and disease rates, the frequency and intensity of scour events during spring freshets, and the maintenance of adequate flows.

Everest and Chapman (1972) found age-0 steelhead residing over cobbles in water velocities of <0.15 m sec^{-1} (0.5 fps) and depths of 0.15-0.31 m (0.5-1.0 ft). Juvenile steelhead will utilize stream margins and submerged rootwads, debris, large substrate, and logs to provide shelter and cover while rearing in freshwater habitats (Bustard and Narver 1975; Busby et al. 1996; Hilgert and Jeanes 1999; Jeanes and Hilgert 2000, *in preparation*). Both winter and summer juvenile steelhead rear in freshwater for more than one year before migrating to the ocean (Busby et al. 1996).

In the Cedar River most juvenile steelhead migrate after two years rearing in freshwater (Fresh and Lucchetti 2000). In some northern rivers, juvenile steelhead can rear four or five years before migrating to the ocean. Steelhead from British Columbia and Alaska frequently smolt after residing for three years in freshwater (Withler 1966, Narver 1969, Sanders 1985). In most other populations, the modal smolt age is two years. In general, juvenile downstream migration for steelhead smolts occurs from April through May, with peak migration occurring in early May (Fresh and Lucchetti 2000). An early study of steelhead smolt emigration by Pautzke and Meigs (1940) found that steelhead smolts emigrated from the Green River, Washington primarily during April and May.

Distribution

The native distribution of steelhead extended from the Alaska Peninsula to northern Mexico. Presently, spawning steelhead are found as far south as Malibu Creek, California (62 FR 43937). Two different genetic groups (coastal and inland) of steelhead are recognized in North America (Busby et al. 1996). British Columbia, Washington, and Oregon, have both coastal and inland steelhead, while Idaho has only the inland form; California steelhead stocks are all of the coastal variety (Busby et al. 1996).

No summer steelhead have been identified in the Cedar River. The steelhead runs in Washington are differentiated by an arbitrary date of 31 October. Steelhead entering the Cedar River from May through October would be considered summer steelhead (WDFW et al. 1994). Wild winter steelhead are native to the Cedar River and spawn from mid-March through June (WDFW et al. 1994). Hatchery-origin winter steelhead generally begin spawning earlier in the season than do their wild counterparts, but a broad overlap in spawning times does occur (WDFW et al. 1994). Hatchery origin winter steelhead

(Chambers Creek stock) have been stocked into the Lake Washington system as fry or smolts since the 1930's (WDFW et al. 1994).

Status

The Lake Washington basin is considered to have only one stock of native/wild steelhead trout. Lake Washington steelhead have been placed into the Puget Sound ESU, along with 53 other steelhead stocks, by the NMFS (Busby et al. 1996). Total run size for the major stocks of this ESU was estimated at 45,000, with natural escapement estimated at approximately 22,000 steelhead (Busby et al. 1996). Adult Lake Washington winter steelhead have historically experienced a high rate of predation by California sea lions (*Zalophus californianus*) below the fish ladder at the Locks. Nehlsen et al. (1991) considered salmonid stocks throughout Washington, Idaho, Oregon, and California and enumerated all stocks that they found to be extinct or at risk of extinction. They listed Lake Washington winter steelhead at moderate risk of extinction.

Historically, natural production has occurred in the Cedar River, Issaquah Creek, and north Lake Washington tributaries such as Bear Creek and the Sammamish River (WDF et al. 1994). The natural Lake Washington spawning stock of winter steelhead is managed for an escapement of 1,600 fish, representing approximately 7% of the estimated natural escapement of all steelhead within the Puget Sound ESU. Natural spawner escapement in the Cedar River has ranged from 70 to 2,575 from 1983 through 1997, and averaged 800 adults (City of Seattle 1998). In recent years, the escapement target of 1,600 adults was only met during the period 1985 through 1986 (WDFW et al. 1994; City of Seattle 1998). Following 1986, steelhead escapement in the Cedar River fell to a low of 70 adults in 1994 and recently rebounded to 616 fish in 1997 (City of Seattle 1998). Winter steelhead stocks in the Lake Washington basin were rated as depressed by the WDFW (WDFW et al. 1994).

2.3.1.6 Coastal Cutthroat Trout

Species Description

The coastal cutthroat trout differs from all other trout by its profusion of small to medium-size spots of irregular shape (not round as on most interior cutthroat subspecies), which are distributed more or less evenly over the sides of the body, onto the head, and often onto the ventral surface and anal fin. Of all interior subspecies, only the Lahontan cutthroat trout has spots distributed like those of the coastal subspecies, but the spots of Lahontan cutthroat trout are larger, rounder, and fewer. The spots on coastal cutthroat trout are densely packed.

The coastal form does not develop the brilliant colors of some interior subspecies. Sea-run individuals are silvery, and the silvery skin deposits often obliterate body spots. Resident freshwater fish tend to be darker with a coppery or brassy sheen. A rose tint is sometimes apparent on the sides and ventral regions of sexually mature fish, especially in lake-dwelling stocks.

Life History

In the Lake Washington basin, the coastal cutthroat is the only species of cutthroat trout known to naturally occur and is present in both resident and anadromous forms. The population of sea-run cutthroat in the Lake Washington Basin is most likely a native stock, although coastal cutthroat were stocked in numerous Lake Washington steams as early as 1895 by the US Bureau of Fisheries (Crawford 1979).

The life history of the coastal cutthroat trout is probably the most complex and flexible of any Pacific salmonid (Wydoski and Whitney 1979, Johnson et al. 1994, Northcote 1997). Cutthroat trout in the Lake Washington Basin exhibit fluvial, adfluvial, and anadromous life histories. Little is known about the relative proportion of each life history in this population, however there is evidence that a large portion of the Lake Washington population exhibits an anadromous life history pattern. This diversity in life history may reflect an adaptive generalist strategy that allows coastal cutthroat trout to exploit habitats not fully utilized by other salmonids (Johnston 1982, Northcote 1997a).

Coastal cutthroat trout may return to freshwater feeding/spawning areas from late June through March; re-entry timing is consistent from year to year within streams, but varies widely between streams (Giger 1972, Johnson et al. 1994). As in other species of anadromous salmonids, entry to large rivers occurs consistently earlier than to shorter coastal rivers (Giger 1972, Johnston and Mercer 1976, Johnston 1982).

Anadromous cutthroat trout spawning typically starts in December and continues through June, with peak spawning in February (Pauley et al. 1989, Trotter 1989). Non-migratory coastal cutthroat trout typically mature at an early age (2-3 years) whereas sea-run cutthroat rarely spawn before age 4 (Trotter 1991). Larger fish, because of their size, can obtain the best spawning sites and produce larger eggs (Trotter 1997). Redds are primarily built in the tails of pools in streams with low stream gradient and low flows, usually less than 0.3 m^3 sec^{-1} during the summer (Johnston 1982, Wydoski and Whitney 1979, Johnson et al. 1994). Preferred water temperatures for spawning and incubation ranges from 6^oC-17^oC; cutthroat are generally not found in water temperatures exceeding 22^oC (Johnson et al. 1994).

Coastal cutthroat trout will often spawn in the smallest headwater streams and tributaries used by any salmonid species (Palmisano et al. 1993). Generally, spawning occurs upstream of coho salmon and steelhead spawning zones, although some overlap may occur (Lowry 1965, Edie 1975, Johnston 1982). It is believed that this choice by coastal cutthroat trout of spawning sites in small tributaries at the upper limit of spawning and rearing sites of coho salmon and steelhead has evolved to reduce competition for suitable spawning sites and reduce competitive interactions between YOY coastal cutthroat trout and other salmonids.

Cutthroat trout are iteroparous, and the incidence of repeat spawning appears to be higher than in steelhead (Sumner 1953, Giger 1972, Busby et al. 1996). Some fish have been documented to spawn each year for at least five years (Giger 1972), although some do not spawn every year (Tomasson 1978) and some do not return to seawater after spawning, but instead remain in fresh water for at least a year (Giger 1972, Tomasson 1978).

Eggs begin to hatch within 6-7 weeks of spawning, depending on water temperature; alevins emerge as fry between March and June, with peak emergence in mid-April (Giger 1972, Scott and Crossman 1973). At emergence, fry quickly migrate to channel margins and backwaters, where they remain throughout the summer (Glova and Mason 1976, Moore and Gregory 1988). Coastal cutthroat trout are found in streams with channel gradients that vary from low (<2%) to moderate (2-3%) or steep (>4%), with narrow widths (0.7-3.0 m) (Hartman and Gill 1968, Edie 1975, Glova 1978, Moore and Gregory 1988, Jones and Seifert 1997), and often in small watersheds with drainage areas under 13 km^2 (Hartman and Gill 1968).

There is some disagreement in the literature regarding the preferred habitat type of coastal cutthroat trout fry. When they are the solitary species present, YOY coastal cutthroat trout are more abundant in pools, but use riffles and glides as well (Glova 1984). In contrast, in sympatry with coho fry and sculpins, coastal cutthroat trout are fairly evenly distributed between all three habitat types (Glova 1978; 1987). The reduced use of pools while in sympatry has been interpreted as evidence that coastal cutthroat trout are relegated to riffles by socially dominant coho salmon (Glova 1978; 1984; Johnston 1982; Trotter 1997). Other authors have found that underyearling coastal cutthroat trout select the shallower and faster waters in riffles (June 1981; Bisson et al. 1982, Bisson and Sedell 1984; Mitchell 1988) but may reduce their use of this habitat type in the presence of steelhead (Bisson et al. 1982). In winter, coastal cutthroat trout move to pools near log jams or overhanging banks (Bustard and Narver 1975).

Because sea-run cutthroat spend a considerable proportion of their life cycle in fresh water, stream rearing habitat is a major factor in their survival and productivity (Palmisano et al. 1993, Johnson et al. 1994). Individuals that migrate to the sea live in these larger streams for another 2-5 years (usually 3) before migrating to the Pacific Ocean (Wydoski and Whitney 1979; Johnson et al. 1994). The seaward migration of smolts occurs in April and May and coincides with steelhead smolt emigration (Grette and Salo 1986). Some coastal cutthroat trout do not outmigrate to the ocean, but remain in small headwater tributaries. Still others migrate only into rivers or lakes even when they have seawater access (Nicholas 1978; Tomasson 1978; Moring et al. 1986; Trotter 1989).

Distribution

The northern (and western) extent of coastal cutthroat trout distribution is the Prince William Sound area of southern Alaska, bounded by Gore Point on the Kenai Peninsula. The southern limit is the Eel River, California. Coastal cutthroat trout occur on all the numerous islands with suitable habitat off the coast of British Columbia and southern Alaska. Typically, they do not occur far inland, usually less than 150 km from the coast. The farthest natural inland penetration is in the headwaters of the Skeena River, British Columbia. Throughout this range, both sea-run and non-migratory stocks are found. Many of the nonmigratory stocks live in lakes and show morphological specializations for lacustrine life.

Status

The anadromous or sea-run form of the coastal cutthroat trout has recently undergone a comprehensive status review for west coast stocks for listing under the Endangered Species Act. The NMFS identified six ESU's within their range. The USFWS and NMFS listed one stock in the Umpqua River because of its geographic isolation, genetic distinctiveness, and low population size. On 5 April 1999, the NMFS indicated the Puget Sound ESU is not warranted for listing. Although the status of all Washington sea-run stocks has not been fully assessed, most are considered depressed or critical because of severe habitat degradation and chronically low returns. Habitat degradation has resulted from many factors, including stream diversion, urban development, agriculture, timber harvest, and road construction. All forms of the coastal cutthroat trout appear to be highly vulnerable to logging activities, showing marked population declines for 6-8 years following clearcut operations in Oregon (Behnke 1992). Sea-run coastal cutthroat are at some risk of extinction due to pervasive continuing declines (Nehlsen et al. 1991).

In recent years, resident cutthroat trout have increased in abundance in the Lake Washington Basin (Fresh 1994). Widespread urbanization around Lake Washington has created more marginal conditions for other salmonids and cutthroat trout are able to use these habitats more successfully than other trout and salmon (Scott et al. 1986). Notably, in areas of sympatry with other salmonids, cutthroat trout appear to take a subdominate role (Johnson et al. 1994); therefore, apparent population increases in the Lake Washington Basin may reflect increased availability of marginal habitats, from which other salmonid species have disappeared.

The various life histories and population status for salmonids occurring in Lake Washington are presented in Table 8. Except for cutthroat, all species are considered depressed and will benefit from the addition of littoral habitat in Lake Washington.

Table 8. Review of salmonid life histories that occur in the Lake Washington basin, Seattle, Washington.

Parameter	**Fish Species**			
	Sockeye	**Chinook**	**Coho**	**Steelhead**
Mean Escapement (1987-1996)	166,500	901	3,450	598
Lowest Escapement on Record	26,000	245	200	70
Escapement Goal	350,000	1,500	15,000	1,600
Status	depressed	depressed	depressed	depressed
Spawning				
Duration	Sept-Feb	Sept-Nov	Oct-Jan	Mar-Jun
Peak	mid Oct-mid Nov	Oct	Nov	May
Emergence				
Duration	Jan-May	Feb-May	Mar-Apr	May-Aug
Peak	Mar-Apr	Feb-Mar	Mar	Jul-Aug
Freshwater Residence				
Habitat Type	Lake	River	Tributary	River
Duration (yrs)	0.5-2.3	0.5-1.0	1.5	2.0
Timing of Outmigration				
Duration	Apr-Jun	May-Jul	Apr-May	Apr-May
Peak	May	June	Early May	Early May
Marine Residence				
Range (yrs)	1-3	2-5	0.5-1.5	2-3
Typical (yrs)	2	4	1.5	2-3

3. METHODS

3.1 LITERATUE REVIEW

Both published and “gray” literature relating to shoreline structures and activities in cold, freshwater lakes was reviewed along with pertinent information from warmwater, riverine, and marine systems. Primary searches targeted all relevant electronic databases, followed by secondary reviews of literature cited sections of pertinent items collected during primary searches. Literature collected includes peer-reviewed journal articles, theses/dissertations, books, and technical documents. The literature collected for the review constitutes the majority of available relevant documents, with only the most inaccessible documents omitted.

3.2 FIELD SURVEYS

3.2.1 Beach Seine Surveys

Beach seine surveys were used to determine monthly changes in diel distribution and abundance of salmon fry, overyearlings, and potential predators in the nearshore area of Seward Park. Beach seine surveys were conducted at six permanent sites selected on the shoreline of Seward Park during in 1999. At each site, morning and night surveys were conducted once a month from April through June (a single sample = combined catch from two beach seine hauls). All fish were identified and enumerated. The steelhead and rainbow trout were not positively identified during fish processing because of the depressed condition of the Lake Washington steelhead stock all rainbow/steelhead were immediately released, therefore this report does not distinguish between the two.

The seine (36.7 m in length) had a maximum depth of 3.1 m in the center with a 9.1 m length bag. The wings were composed of 3 cm mesh with 3.2 mm knotless nylon mesh bag. The net was deployed from shore using a boat and was pulled in a semicircle around the littoral zone. The net coverage was approximately 1,416 m^3, but this varied depending on the slope (i.e., the point at which the slope of the bottom increases dramatically). The net coverage was calculated by estimating that if the net was 36.7 m in length and 2 m in depth and had 30 m rope leads, the maximum volume that could be captured was 2,202 m^3. However, frequently the net was set at an angle to the shoreline (not parallel) and the minimum volume swept would be a right triangle with sides of 36.7 m, 30 m and approximately 21 m, for a volume of 630 m^3. The volume captured (1,416 m^3) is equivalent to the mean the maximum and minimum hypothetical volumes.

General observations for littoral and limnetic surveys included weather, water temperature. Substrate type, and presence of aquatic vegetation, specifically Eurasian water milfoil, was noted for each of the littoral sites. Water temperature was monitored at selected sample sites during littoral sampling.

3.2.2 Snorkel Surveys

Two divers were used to survey each site. The snorkel sites were 50 m by 15 m in size. Direct enumeration procedures were used to count the total number of fish within each sample unit. The unit was divided into equal transects (50 m by 7.5 m) between the two divers. Divers proceeded in the same direction paralleling the shoreline and counted all fish within their transect. Fish were identified by species and size class and relayed to an observer standing on shore. To avoid recounting fish, divers stayed adjacent to each other, moved at the same speed, and only counted fish that passed them. Snorkeling was preformed once during the daylight hours and once during night hours on each survey occasion.

3.2.3 Spawning Surveys

A spawning survey was conducted in the first 15 m of wetted nearshore habitat around Seward Park during the Fall of 1999. Three different visual techniques (snorkeling observations, boat observation, and helicopter observation) were used in an effort to locate potential shore spawning sockeye salmon and/or redds.

4. RESULTS

4.1 LITERATURE REVIEW

4.1.1 Shoreline Bank Protection

Within lakes, littoral regions are extremely important to the structure, function, and integrity of lake ecosystems (Bartoo 1972; White 1975; Hall and Werner 1977; Eggers et al. 1978; Gelwick and Matthews 1990; Benson and Magnuson 1992; Beauchamp et al. 1994). Evidence suggests that transfer of food energy from the littoral zones lakes may influence overall fish production and biomass (Boisclair and Leggett 1985). Most lake-resident fish, including those that inhabit cool or coldwater offshore habitats in summer, seasonally rely on littoral areas for spawning and rearing (Becker 1983). Moreover, many of these species make diel and seasonal use of littoral regions for foraging (Scott and Crossman 1973; Becker 1983). In addition to species that utilize these areas seasonally, many species use littoral regions throughout the year, and throughout their entire life cycle (Becker 1983).

The relationships between fish and habitat have been the subject of numerous ecological investigations. The fact that fish are habitat specialists has been well established by studies conducted in a variety of freshwater habitats (Gorman and Karr 1978). The most extensive literature on fish-habitat relations and effects of habitat alterations on fish populations is from streams where two general areas relevant to shoreland management have been particularly well studied, including the role of complex in-water habitat and the role of riparian vegetation. Many of the concepts developed in stream systems are equally relevant to lake systems. The importance of structurally complex habitat has been demonstrated to affect a wide range of fishes and other stream biota, including salmonids (Marcus et al. 1990), insects (Minshall 1984), and salamanders (Hawkins et al. 1983). Woody debris and complex benthic substrate directly provide cover and habitat for food production and also affect the hydraulics that shape the stream channel (Hawkins et al. 1993). Angermeier and Karr (1984) demonstrated that removal of complex woody habitat in a warmwater stream led to a reduction in the number of fish, while no change was observed in the same stream where habitat remained intact. Schlosser (1982) observed similar results in a comparative study of two warmwater streams, one of which was subject to modification including removal of riparian vegetation and channel straightening. Removal of complex substrates from streams not only eliminates spawning habitat and refuge cover but also changes the processes (hydraulics, channel formation) to which natural communities are adapted.

The role of habitat in the maintenance of healthy fish assemblages is as important as the role of clean water. In fact, assessments of stream fish community health commonly use indices (metrics) that quantify degradation, including habitat destruction (Fausch et al. 1984). Although this approach, commonly known as an index of biotic integrity or IBI (Karr et al. 1986), is not widely accepted in lakes, however, ample evidence demonstrates the importance of fish-habitat relationships in lakes.

The effects of habitat structure on predator-prey relationships have also been investigated in lacustrine systems. In particular, macrophytes can provide refuge from predators (Mittlebach 1981; Savino and Stein 1982). Depending on macrophyte density, predators may also find profitable foraging areas associated with aquatic plants (Werner et al. 1983; Mittlebach 1984). These studies demonstrate that interspecific relationships are influenced by habitat structure, but the manner in which habitat modification resulting from shoreline development affects these relationships has not been investigated.

While most studies of fish-habitat interactions focus on natural habitat features, some recent studies have more directly addressed the issues associated with shoreline development. For example, distribution of woody debris in lakes changes with riparian forest management practices (Peffers 1995) and with residential development of lakeshores. Other studies have focused on interactions between modified habitats and fishes. Beauchamp et al. (1994) investigated use of habitat including piers and cribs, by fish in Lake Tahoe. Increased habitat complexity led to more fish; however, they also acknowledged the need to consider aesthetics and other uses of the water before using artificial structures for fish enhancement. Beyond these observed relationships, Beauchamp et al. (1994) also speculated that solid bulkheads, by simplifying habitat, would have negative effects on local fish densities. Ward et al (1994) studied the effects of harbor development on migratory juvenile salmonids. Although they concluded that waterway developments posed few risks to juveniles moving through the area, they also expressed concern regarding the effects of bulkheads that would reduce the variety of habitat available. Leslie and Timmins (1994) observed that both species diversity and individual fish abundance were related to structural complexity of the habitat among species and life stages and expressed concern that many species present were restricted to fragmented, remnant niches. Differences in fish abundance associated with shoreline development were detected in Spirit Lake, Iowa (Bryan and Scarnecchia 1992). The developments in this lake were associated with reduction of aquatic vegetation.

To date, definitive studies that quantify habitat and fish assemblages associated with specific types of shoreline structures have not been conducted. Changes in habitat and resulting impacts on fish may be directly attributed to a particular type of shoreline erosion control structure or may be the result of other types of development that typically accompany placement of structures. The available literature supports the view that habitat modifications can result from shoreline development and that those modifications may affect the fish community. Because fish are known to use and associated with specific habitat types, elimination of habitat features or simplification of habitat is expected to alter distribution of fishes. The hypothesized effects of a retaining wall primarily stem from alteration of habitat. Possible outcomes include: (1) removal of cover in the aquatic/terrestrial transition zone, (2) alteration of depth profile, (3) scouring by wave energy deflected by structures, and (4) simplification or homogenization of habitat. Any of these changes might lead to differences in use by and abundance of fishes in Seward Park littoral zone habitat.

Littoral zones generally change more dramatically and rapidly than limnetic areas because they are influenced by factors originating from both the lake as a whole and from the surrounding landscape (Crowder et al. 1996). Considerable changes have occurred in the littoral areas of both Lake Washington and Lake Sammamish. The completion of the Locks, to create a direct water route between Lake Washington and Puget Sound, and diversion of the Cedar River into Lake Washington lowered the lake's level about 3.0 m. This exposed approximately 5.4 km^2 of previously shallow water habitat and reduced the lake's surface area 7.0%, decreasing the shoreline length by 16.9 km (a 12.8% reduction), and eliminating much of the lake's wetlands (Chrzastowski 1981). Lake levels are regulated by the Locks and kept within about a 1 m range. Historically, lake elevations varied up to 2.1 m during flood events (Chrzastowski 1981). The highest lake levels now occur in summer and seasonal lows occur in winter which is opposite of the pattern exhibited by unregulated lakes in the region. Because distribution of aquatic macrophytes in lakes can be limited by the occurrence of extremely low water levels (Cooke et al. 1993), the stable lake levels have probably promoted the expansion of aquatic macrophytes, which are now dominated by the non-native Eurasian watermilfoil *Myriophyllum spicatum*.

Lake Washington's shoreline clearly is not pristine habitat. Dredging, filling, bulkheading, removal of shoreline vegetation, and the construction of piers, docks, and floats has occurred as the watershed has been developed. The recent survey of the City's shorelines (Parametrix and NRC 1999) demonstrates a high degree of development that has eliminated or altered most shallow water shoreline habitat. For example, an estimated 82.0% of the Lake Washington shoreline has been bulkheaded and approximately 4.0% of the lake's surface area within 33 m of shore has been covered with residential peirs (Parametrix and NRC 1999). As a result of these changes and the lowering of water levels, little natural shoreline remains in either lake, which has likely reduced the amount of woody debris in littoral areas (Christensen et al. 1996). The City's parks provide the only substantial exception to this highly modified shoreline condition. Park shorelines are relatively natural, although light riprap is typically present. City parks bordering Lake Washington include, Seward, Lake Washington Boulevard, Leshi, Madison, Magnuson, and Matthews Beach Parks. City park ownership accounts for approximately 35% of shoreline use (Weitkamp and Ruggerone 2000).

One probable impact of littoral zone changes has been a decrease in sockeye beach spawning areas due to elimination of their spawning beds by aquatic macorphytes. Eurasion water milfoil was introduced to Lake Washington in the late 1960's. Milfoil spread throughout the lake very quickly and covered more than 380 ha (942 ac) of littoral habitat by 1981 (Patmont et al. 1981). Shoreline development may also have contributed to elimination of beach spawning habitat by altering substrate composition and water circulation patterns of spawning areas.

Based upon results of studies in other lakes, it is likely that the types of littoral zone changes observed in Lake Washington have altered the composition, diversity and abundance of fish communities (Bryan and Scarnecchia 1992; Beauchamp et al. 1994; Christensen et al. 1996; Weaver et al. 1997). The amount and spatial patterning of macrophytes can directly affect littoral zone fish abundance and assemblage structure (Bryan and Scarnecchia 1992; Weaver et al. 1997). For example, moderate amounts of macrophytes usually increase abundace of fish (Bryan and Scarnechhia 1992) while high densities of macrophytes can cause localized mortalities of fish due to dissolved oxygen depletion (Frodge et al. 1995). In addition, the type of complex habitat provided by piers, docks, and bulkheads can increase fish abundance (Beauchamp et al. 1994). It is difficult, however, to predict the net effect of changes in littoral zones. For example, while shoreline development and macrophytes may result in more habitat for juvenile fish in the lake, they may also enhance habitat for predators, such as the non-native smallmouth bass (Bryan and Scarnecchia 1992) and northern pikeminnow (Gregory and Levings 1993).

Review of the literature obtained on littoral zone fish community interactions and the effects of shoreline modification indicate that these topics are poorly understood throughout the country, especially in the Lake Washington system. One source of fish community interactions for Lake Washington was obtained from White (1975). He surveyed littoral areas for fish assemblages and determined that there was not a significant difference between either the seasonal trends or species composition of shorelines with piers and bulkheads versus control areas. White (1975) indicated that the substrate of the littoral area is the most important determinant of fish utilization, not the presence of piers or bulkheads.

4.1.2 Previous Studies Conducted at Seward Park

As part of the Lake Washington Ecological Evaluation Program, the Corps performed a study looking at the early lake life of sockeye salmon fry in Lake Washington during 1994 and 1995 (Martz et al. 1996). The study looked at the early lake life (defined as the first several months of lake residence) of sockeye fry over two years, investigating several aspects of their ecology including diet, growth rates, mortality, predators, abundance, and horizontal and vertical distribution. The focus of this report discussed preliminary data collected concurrently with the study protocol evaluation, horizontal and vertical distribution, abundance, growth rate, competitor and predator populations. Martz el al (1996) sampled 11 different locations throughout Lake Washington. One site (Site 10) was located on the East Shore of Seward Park.

Martz et al. (1996) found that the majority of the sockeye fry captured throughout Lake Washington occurred in the limnetic zone which concuured with previous studies. To their surprise however, a large proportion of the limnetic fry were captured below 20 m during nighttime surveys which contrasted to the results obtained by (Narver 1970) and Woodey (1972) who determined that sockeye fry foraged at night above the 15 m range during spring and summer. A small percentage of sockeye fry did utilize the Lake Washington littoral zone, however. It appears that sockeye fry utilize this habitat type early upon their entry into Lake Washington. Sockeye fry are hypothesized to use littoral zones at night for the first month and then move into deeper limnetic habitat as they grow larger. Overall, there was not a significant difference between day and night catches of sockeye fry in the littoral zones of Lake Washington (Table 9) (Martz et al. 1996). More sockeye were captured in the littoral areas during nighttime surveys early in the migration season (February and March), however. The authors hypothesized that the majority of these fry had recently immigrated from the Cedar River. Littoral areas also provide a substantial portion of the habitat available to recently emerged beach spawning sockeye fry. Historically, this component of the sockeye population in Lake Washington was comprised of 3,000-9,000 spawning sockeye. Numbers of beach spawning sockeye have decreased recently, but remain a valuable element to the population.

Table 9. Seine catch at Seward Park, Seattle, Washington, 1994-1995. Species abbreviation are as follows: Sock = sockeye; Chin = chinook; RBT = rainbow trout; CTT = cutthroat trout; Pea = peamouth chub; YP = yellow perch; Smelt – longfin smelt; PM = northern pikeminnow; LS = largescale sucker; TS = three-spine stickleback; Sun = unidentified sunfish/bluegill; Cott = unidentified sculpin (source = Martz et al. 1996).

Date	**Sock (fry)**	**Sock (smolt)**	**Coho**	**Chin**	**RBT**	**CTT**	**Pea**	**YP**	**Smelt**	**PM**	**LS**	**TS**	**Sun**	**Cott**
							1994							
14 Feb (day)						1								30
14 Feb (night)		2								13				12
15 Mar (day)	8			2			1			1				15
19 Apr (day)												1		17
17 May (day)	1			1			24	11				67		15
							1995							
6 Feb (night)	8				1			1	5	5		8		34
27 Feb (night)	3						1	1		2		1		37
28 Mar (day)										6		1		20
22 Mar (night)		11	1			1				7		7		11
2 Apr (night)		17		1		1				6		433		15
18 Apr (night)		4	2	2			1			2		115		
21 Apr (day)	3	1		5								1		
9 May (night)				1	1		147	29				788		43
19 May (day)		7		10	17		350	25				150		
30 May (night)			1		46		31	80		14	7	99	1	64
19 Jun (day)					13			6		4	9	25	8	2
19 Jun (night)					34			8		31	1	77	3	82

4.2 FIELD SURVEYS

4.2.1 Beach Seine Surveys

All five salmon and trout species present in Lake Washington watershed (not including whitefish) were captured during day and nighttime beach seine surveys conducted on 20 April, 26 May, and 12 June 2000 at Seward Park. Combined, sockeye, coho, chinook, rainbow trout, and resident cutthroat trout comprised less than 10% (167) of the total beach seine catch of 2,770 fish at Seward Park (Figure 10). Three-spine stickleback (80.14%) was the most frequent species captured, followed by *Cottus spp*. (6.03%) and peamouth chub (5.92%). Sockeye (2.31%) and rainbow trout (1.73%) were the most frequently observed salmonid during beach seine surveys. There was not a significant difference between day and nighttime beach seine catches (T-test; p = 0.273), however the power of the performed test was low (0.092) because of a small (3) sample size.

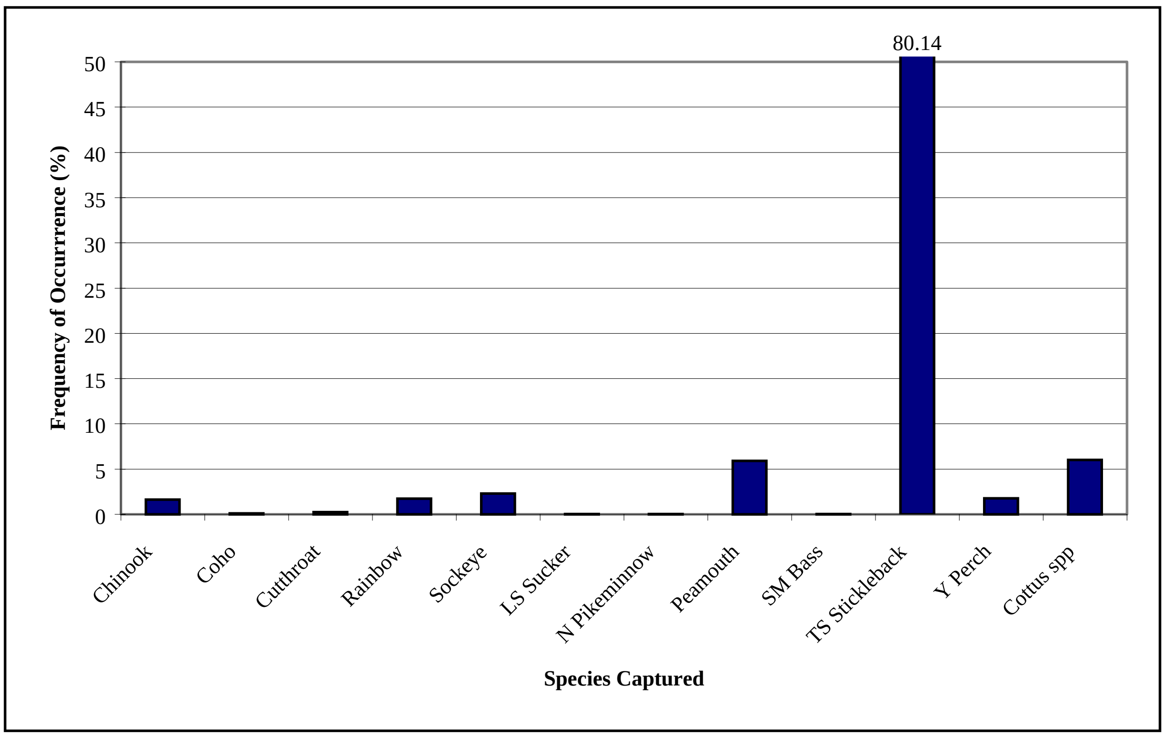


Figure 10. Frequency of occurrence of fish species captured in beach seines conducted along Seward Park, King County, Washington, 2000.

4.2.2 Snorkel Surveys

Combined, 2,806 fish were observed during day and nighttime (paired) snorkel surveys conducted along Seward Park during 1999 and 2000. Except on the first two survey occasions (26 Aug 99 and 24 Sep 99) snorkel surveys were conducted at each site in a paired (day and night) manner (Table 10). The first two snorkel surveys were not paired and only captured a total of 26 fish combined, for these reasons, only snorkel survey occasions that consisted of day and nighttime pairings will be analyzed in this section.

Table 10. Snorkel survey sample coverage of Seward Park, King County, Washington 1999-2000.

	Site 1		**Site 2**		**Site 3**		**Site 4**		**Site 5**		**Site 6**	
Date	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
26-Aug-99	X		X		X		X		X		X	
24-Sep-99	X		X		X		X		X		X	
23-Nov-99	X	X	X	X	X	X	X	X	X	X	X	X
30-Dec-99	X	X	X	X	X	X	X	X	X	X	X	X
12-Jan-00	X	X	X	X	X	X	X	X	X	X	X	X
24-Feb-00	X	X	X	X	X	X	X	X	X	X	X	X
20-Mar-00	X	X	X	X	X	X	X	X	X	X	X	X
19-Apr-00	X	X	X	X	X	X	X	X	X	X	X	X
24-May-00	X	X	X	X	X	X	X	X	X	X	X	X
8-Jun-00	X	X	X	X	X	X	X	X	X	X	X	X
22-Aug-00	X	X	X	X	X	X	X	X	X	X	X	X

Combined, 2,806 fish were observed during paired snorkel surveys conducted along Seward Park. Three-spine stickleback comprised the largest (37%) percentage of fish observed during snorkel surveys (Figure 11). Peamouth chub (30%) and *Cottus spp.* (24%) were the next most frequently observed fish during snorkel surveys. Again, sockeye (5%) were the most abundant salmonid captured, followed by chinook (1%) and coho (1%) salmon. Combined, salmonids comprised 6.78% (191) of the total fish observed during snorkel surveys. More than 68% of the total number of fish observed during snorkel surveys occurred on 19 April 2000 (25%; n=701) and 24 May (43%; n=1,218). The species composition was again, heavily dominated by three-spine stickleback and peamouth chub (Figure 12). Sockeye numbers peaked during snorkel surveys conducted on 19 April 2000 (n=40) and 24 May (n=38), which correspond to

31% (19 April) and 29% (24 May) of the total number (129) sockeye observed throughout the paired snorkel surveys. There was not a significant difference in the mean number of salmonids observed between day and nighttime survey events (Mann-Whitney Rank Sum Test; p=0.341); however, there were significantly (Mann-Whitney Rank Sum Test; p=0.015), more fish observed at night when all fish observed during paired snorkel observations were used in the comparison.

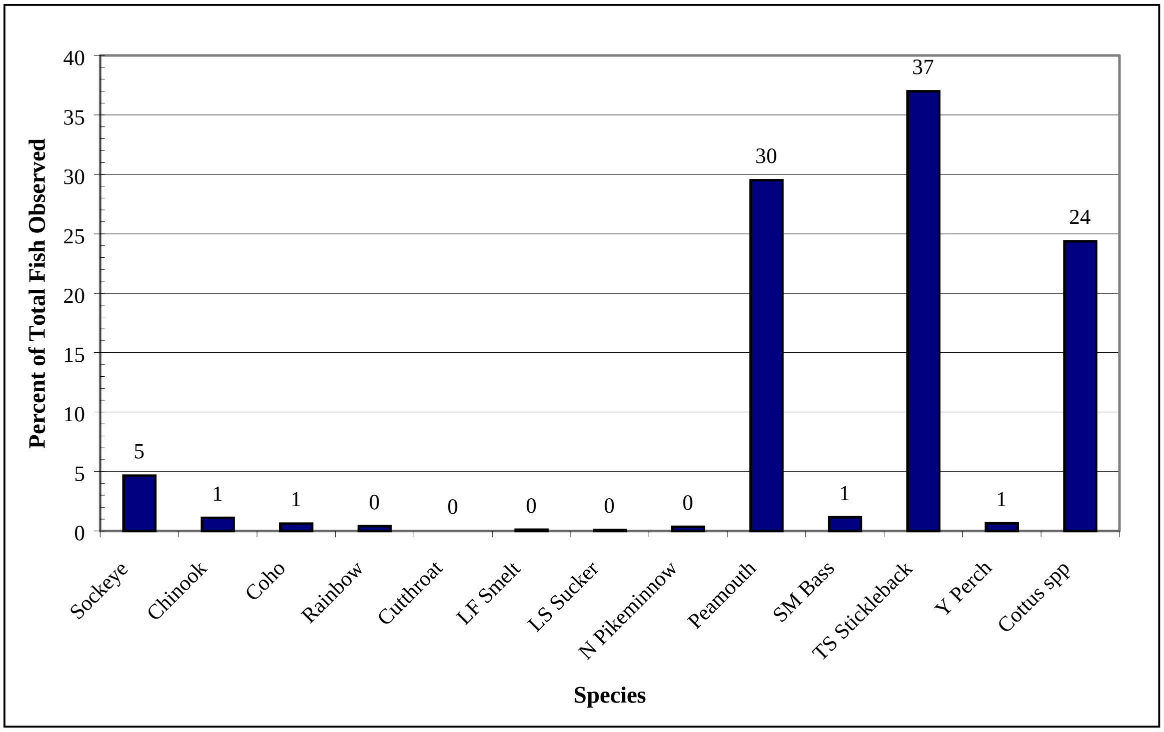


Figure 11. Frequency of occurrence of fish species observed during paired snorkel surveys conducted along Seward Park, King County, Washington, 1999-2000.

4.2.2.1 Juvenile Salmonid Habitat Associations

The habitat associations of juvenile salmonids residing along Seward Park is the main focus of this investigation. For that reason, we will use a sub-set (juvenile salmonid observations) of the paired snorkel survey data set for the following sections. Habitat parameters collected at each survey site consisted of the following; shoreline vegetation, bank angle, bank armor classification, dominant nearshore substrate classification, dominant nearshore vegetation, and water temperature.

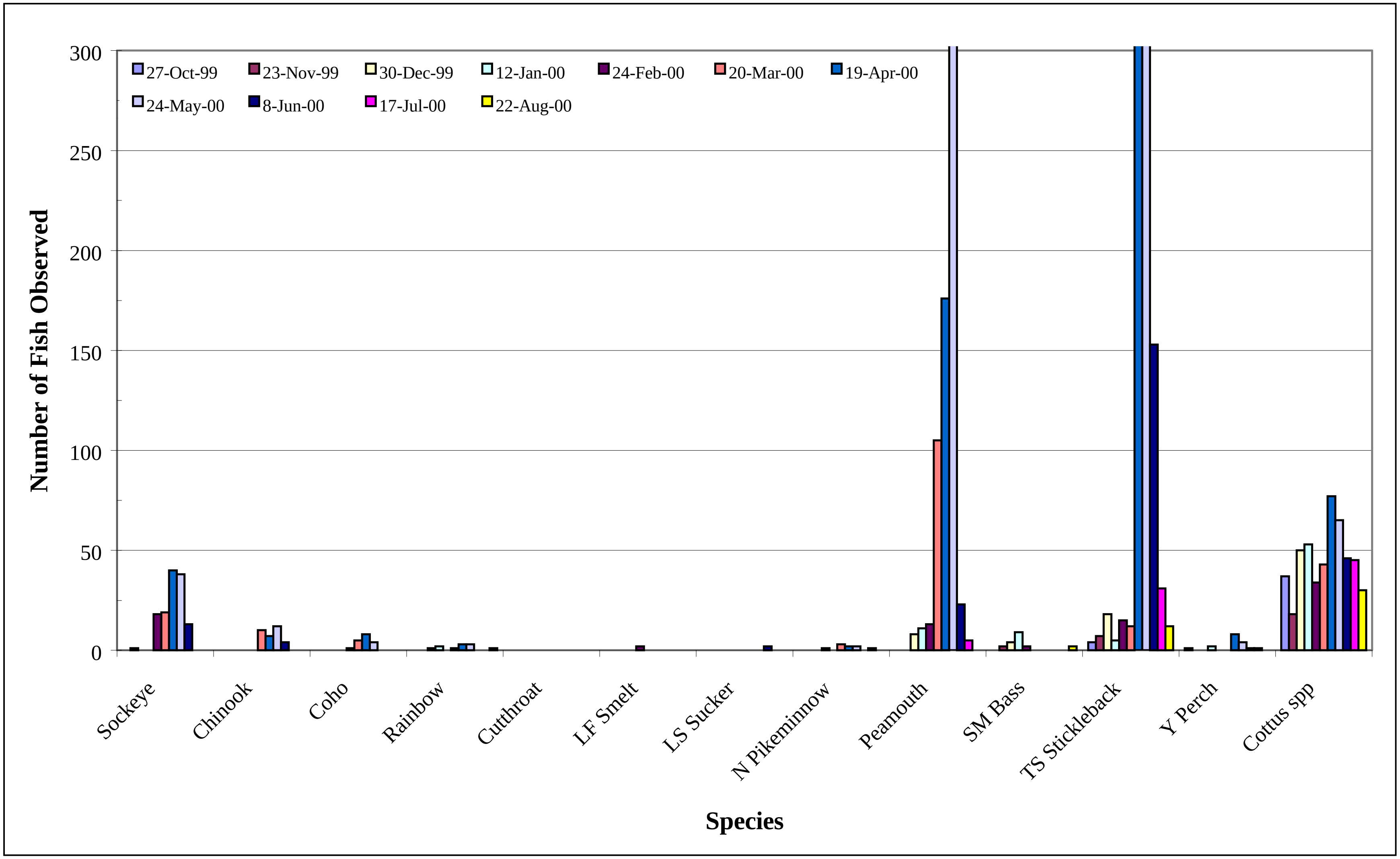


Figure 12. Number of fish observed during paired snorkel surveys conducted along Seward Park, King County, Washington, 1999-2000.

We did not observe enough juvenile salmonids of each species, so we grouped all juvenile salmonids together for the following analyses.

All of the six survey sites had emergent vegetation approximately 10 m out from the shoreline. Likewise, juvenile salmonid abundance was not correlated with water temperature during this study. As previously mentioned, diel habitat use of juvenile salmonids was not significantly different (Mann-Whitney Rank Sum Test; $p=0.3405$), thus the day and nighttime observations were grouped together to form a mean value of juvenile salmonids for each site on each survey day. However, more juvenile salmonids were observed at night (173) compared to daytime (18) observations (Figure 13).

Shoreline Vegetation

The shoreline vegetation was divided into the following categories based upon the proportion of that shoreline vegetation present at each site; grass (no other vegetation present), overhanging vegetation (mostly in the form of large trees), and bank vegetation without overhang (small shrubs and blackberry). Sites 1, 3, and 4 were composed primarily of grass vegetation; Sites 2 and 6 had vegetation that overhangs the water edge; and Site 5 was vegetated but did not overhang the water edge. Throughout the study period, we observed significantly more juvenile salmonids at sites with overhanging bank vegetation (mean = 6.8; SD = 8.9) compared to grass sites (without other vegetation) (mean = 0.7; SD = 1.0) (Student-Newman-Keuls Method; $p<0.05$) and vegetated banks without overhang (Student-Newman-Keuls Method; $p<0.05$) (Figure 14). There was no significant difference between the number of juvenile salmonids observed at sites containing bank vegetation without overhang (mean = 1.7; SD 2.7) and sites containing grass bank cover (Student-Newman Keuls-Method; $p>0.05$).

Bank and Nearshore Bottom Angle

The Seward Park shoreline was divided into the following categories based upon the angle of repose of the bank and slope of the nearshore bottom. The slope of each site was categorized as either gentle (slope ~ 1:8) or steep (slope ~ 1:4). Sites 1,4, and 6 were categorized as gentle, while Sites 2, 3, and 5 were steep. Throughout the study period,

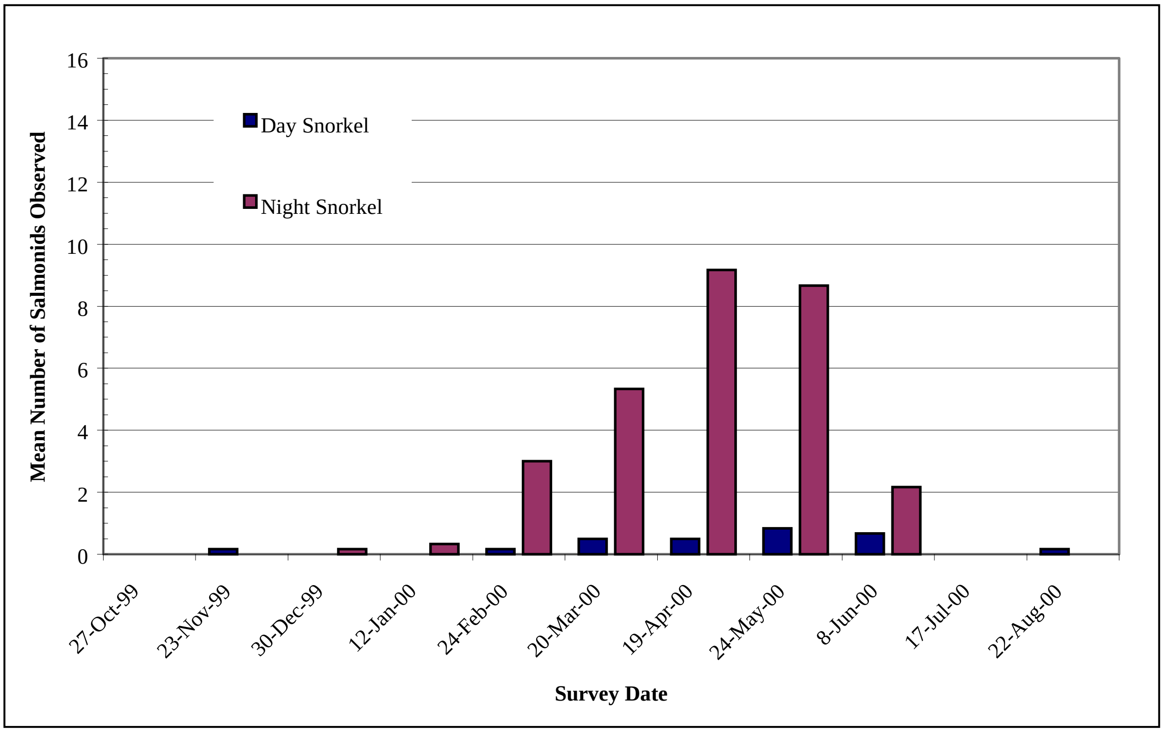


Figure 13. Mean number of juvenile salmonids observed during day and night snorkel surveys conducted along Seward Park, King County, Washington, 1999-2000.

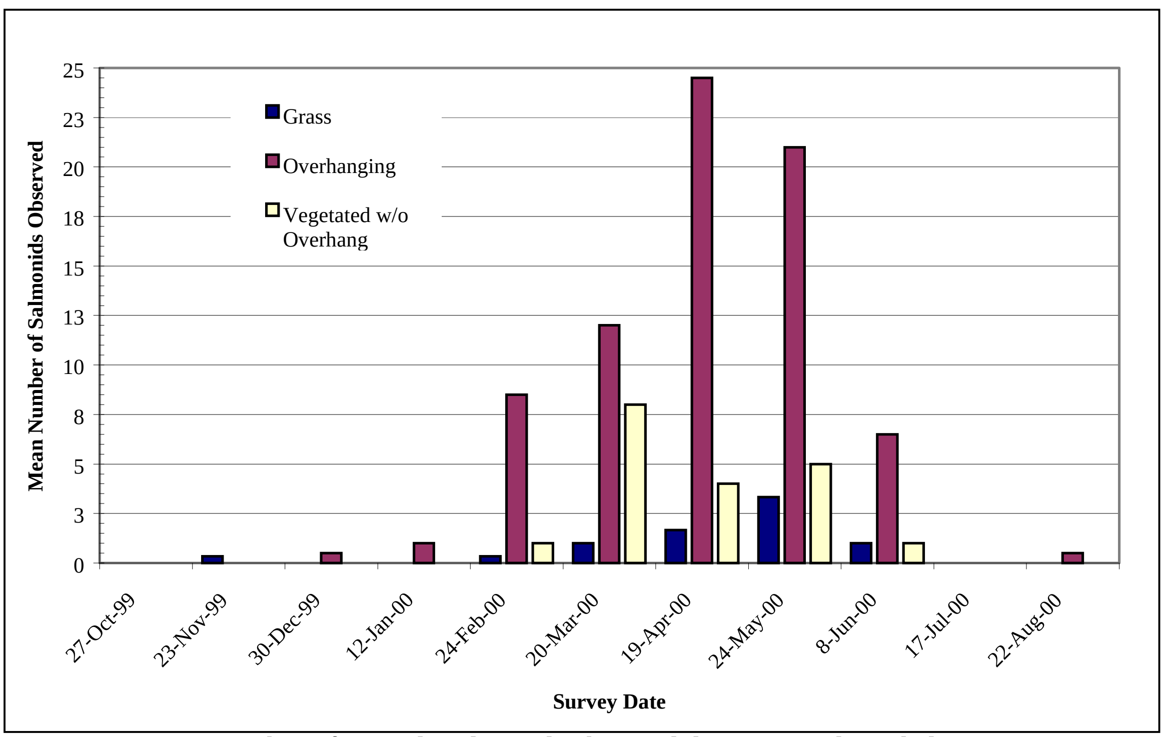


Figure 14. Mean number of juvenile salmonids observed during paired snorkel surveys conducted at sites with different bank vegetation along Seward Park, King County, Washington, 1999-2000.

we consistently observed more juvenile salmonids at sites with gentle sloping banks (mean = 3.7; SD = 4.9) and nearshore bottom slope compared to steep sites (mean = 2.8; SD = 7.9) (Figure 15). However, this difference was not significantly different due to the large variance of gentle-sloping banks (Student-Newman-Keuls-Method; $p=0.264$).

Bank Armor Classification

The Seward Park shoreline was divided into the following categories based upon the composition of the bank material. The bank armor of each site was composed of either concrete bulkhead (Site 1), quarry spalls (Site 3 and 5), or without bank armor materials (Sites 2, 4, and 6). Throughout the study period, we consistently observed more juvenile salmonids at sites without bank armor materials (mean = 4.6; SD = 5.9) compared to both quarry spalls (mean = 0.6; SD = 1.0) and concrete bulkhead materials (Student-Newman-Keuls-Method; $p<0.05$) (Figure 16). There was not a statistically significant difference in the mean number of juvenile salmonids observed at sites containing concrete bulkhead materials (mean = 1.9; SD = 2.9) and quarry spalls, however (Student-Newman-Keuls-Method; $p>0.05$).

Dominant Nearshore Substrate

We used the dominant nearshore substrate classification to compare the mean number of juvenile salmonids observed at each site. The Seward Park shoreline was divided into the following categories based upon the substrate composition of the nearshore habitat. Dominant and sub-dominant substrates were divided into the following categories cobble (7.6-30 cm; 3-12 in), gravel (0.5-7.5 cm; 0.1-3 in), and sand (<0.5 cm; <0.1 in) at each site. Sites 1, 2, 4, and 5 were composed of gravel substrates, while Site 3 was composed of sand, and cobble was the dominant substrate at Site 6. Throughout the study period, we consistently observed more juvenile salmonids at sites with predominately cobble substrate (mean = 9.1; SD = 12.2) compared to both sand (mean = 0.1; SD = 0.3) and gravel (Student-Newman-Keuls-Method; $p<0.05$) (Figure 17). There was not a statistically significant difference in the mean number of juvenile salmonids observed at sites containing gravel (mean = 2.1; SD = 2.8) and sand, however (Student-Newman-Keuls-Method; $p>0.05$).

4.2.3 Spawning Surveys

A single sockeye redd was observed from helicopter on 16 December 1999 immediately south of Sit 6 (southwest shoreline of Bailey Peninsula. Divers confirmed the redd on 30 December 1999 during snorkel observations. The redd was constructed in gravel substrate near large woody debris in approximately 0.8 m (2.6 ft). The presence of adult sockeye carcasses on the beach throughout October, November, and December indicates that some deepwater (>4.5 m; 15 ft) spawning may be occurring along the Bailey Peninsula, however our survey techniques did not adequately survey these habitats.

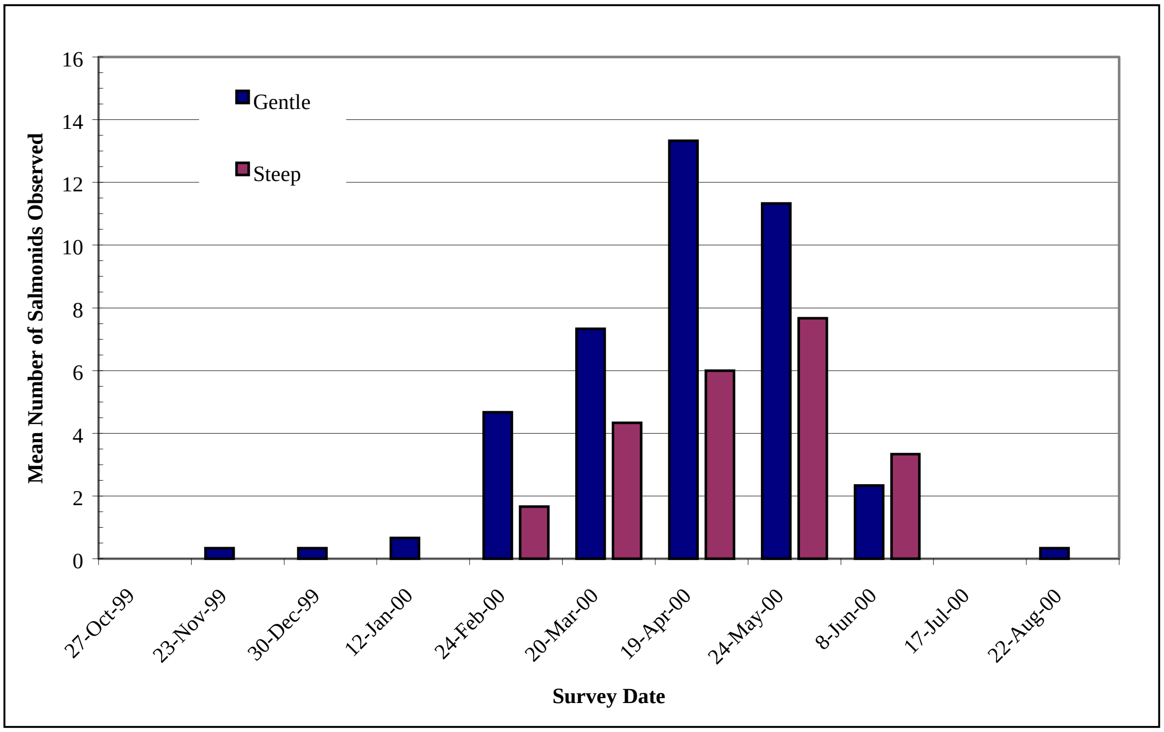


Figure 15. Mean number of juvenile salmonids observed during paired snorkel surveys conducted at sites with different bank and nearshore bottom angles along Seward Park, King County, Washington, 1999-2000.

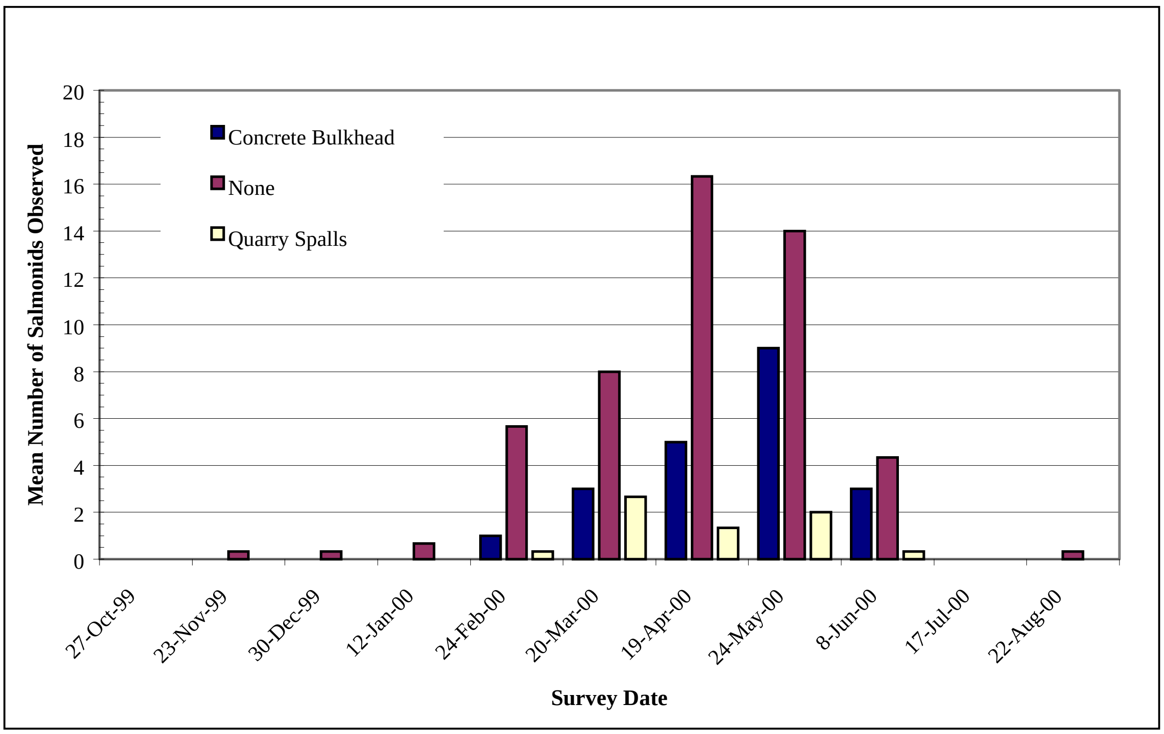


Figure 16. Mean number of juvenile salmonids observed during paired snorkel surveys conducted at sites with different bank armor classifications along Seward Park, King County, Washington, 1999-2000.

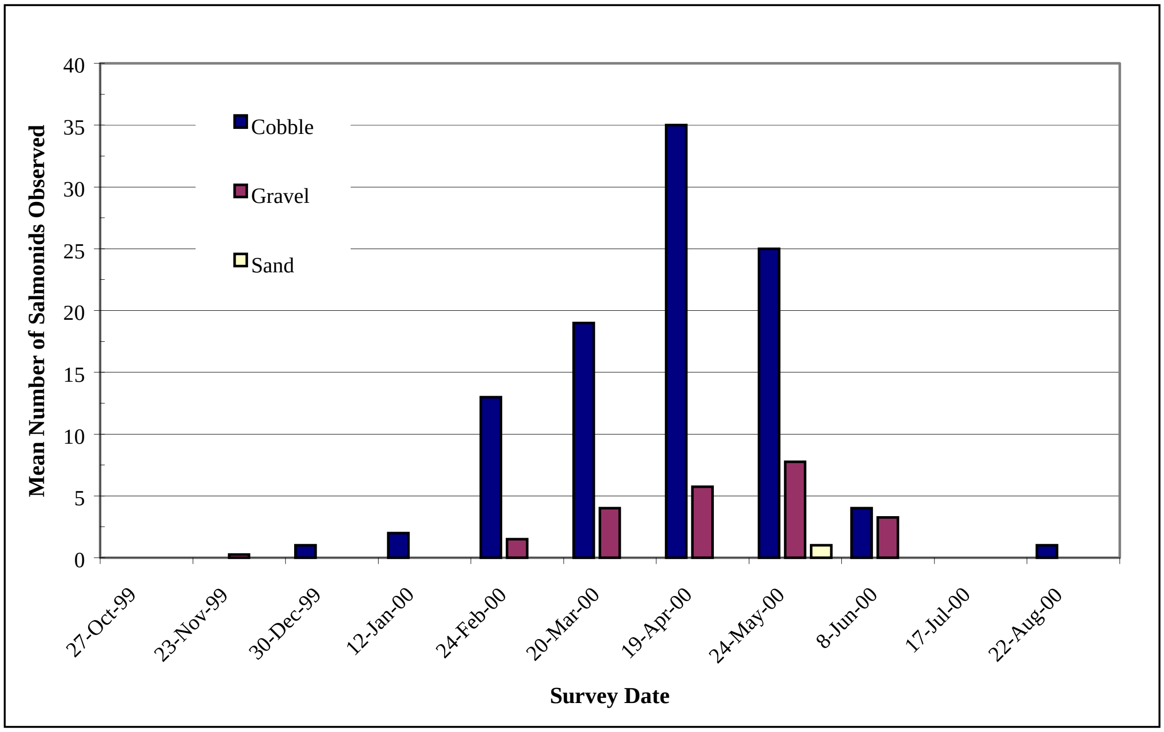


Figure 17. Mean number of juvenile salmonids observed during paired snorkel surveys conducted at sites with different nearshore substrate classifications along Seward Park, King County, Washington, 1999-2000.

5. DISCUSSION

5.1 SALMONID UTILIZATION OF SEWARD PARK SHORELINE

Combined, juvenile salmonids comprised 6.4% (358) of the total fish observed during beach seine and snorkel surveys along Seward Park in 1999-2000 (Figure 18). Sockeye (n = 358) were more than twice as prevalent as the other salmonid species combined (n = 165). Snorkel observations of juvenile salmonids indicated the following habitat relationship should be consulted in the design of bank protection measures for Seward Park (Table 11). We consistently observed more salmonids in nearshore habitats with overhanging vegetation, shallow bank and nearshore bottom slope, no bank armor, and finally cobble substrate. While we did not observe any sockeye redds within the study sites, a single redd was documented south of Site 6. The number of sockeye carcasses found along the beach (main concentration were observed at Site 2) implies that some deepwater spawning is occurring along Bailey Peninsula. Bank stabilization techniques utilizing the above parameters should provide juvenile salmonids with more littoral habitat in Lake Washington. This particular habitat type has been decreased over the years in Lake Washington and appears to provide significant benefit to newly emerged beach spawned sockeye as well as new emigrants from the Cedar River.

Fish observations conducted along the Seward Park shoreline appear to follow the general pattern that other researchers have found to occur in Lake Washington. Eggers et al. (1978) found shallow shoals with aquatic vegetation provide refuge for juvenile sockeye. Martz et al. (1996) also found sockeye utilizing littoral zones, but in lower numbers compared to the limnetic zones in Lake Washington. Like other studies, we observed many fish that are known to be predators of sockeye fry (e.g., *Cottus spp*., northern pikeminnow, coho salmon, and cutthroat trout). The abundance of these fish were not correlated with peaks in juvenile sockeye, however, may be utilizing the area to feed on sockeye fry. The preponderance of peamouth chub, northern pikeminnow, yellow perch, and stickleback in the spring and summer is probably closely related to the species spawn timing.

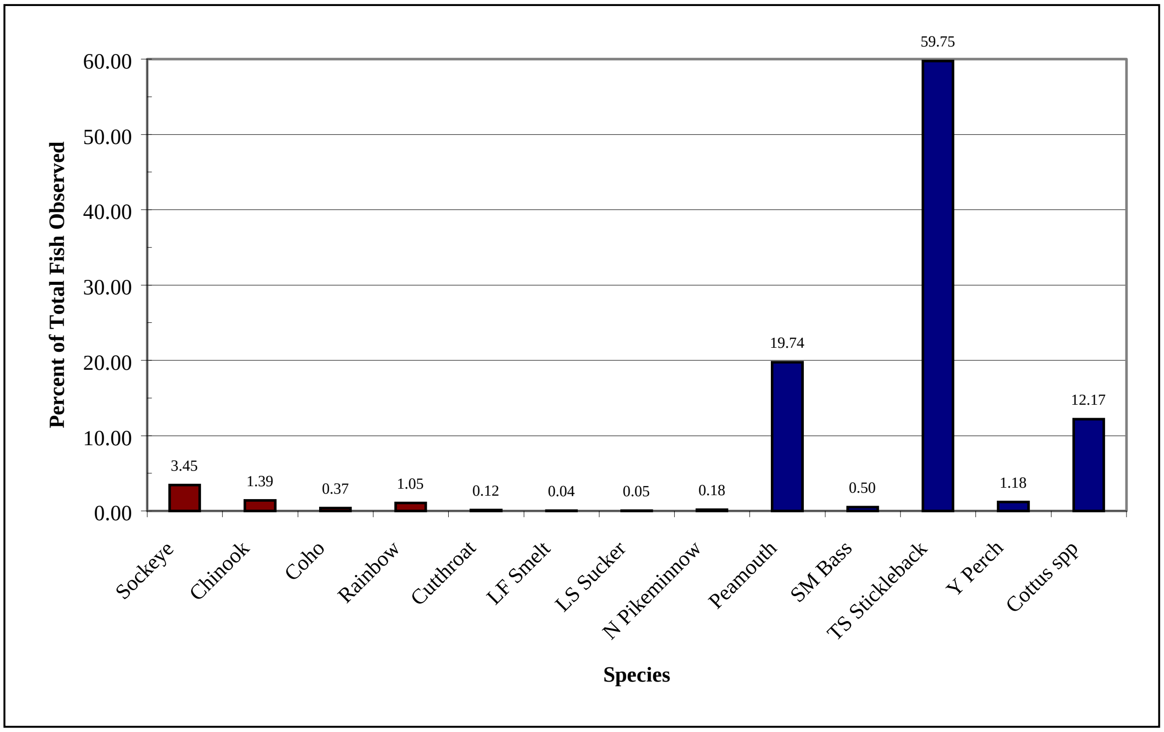


Figure 18. Frequency of occurrence of all fish observed during snorkel and beach seine surveys conducted along Seward Park, King County, Washington, 1999-2000.

Table 11. Juvenile salmonid abundance and habitat relationships observed during snorkel surveys conducted along Seward Park, King County, Washington 1999-2000. Symbols are as follows: - = significantly less than; + = significantly greater than; *- less than but not statistically significant; *+ = greater than but not statistically significant. Table is read vertically, not horizontally.

	Shoreline Vegeatation			**Bank/Nearshore Angle**		**Bank Armor**			**Nearshore Substrate**		
	Grass	**Overhang**	**Veg. w/o Overhang**	**Steep**	**Shallow**	**Bulkead**	**Quarry Spalls**	**None**	**Cobble**	**Gravel**	**Sand**
Grass		+	*+								
Overhang	-		-								
Veg. w/o Overhang	*-	+									
Steep					+						
Shallow				-							
Bulkead							*-	+			
Quarry Spalls						*+		+			
None						-	-				
Cobble										-	-
Gravel									+		*-
Sand									+	*+	

5.2 POTENTIAL ERRORS

5.2.1 Beach Seining

There were several biases inherent in the beach seining portion of this study. Our sampling effectiveness with the seine was influenced by several littoral features (i.e., lake level, substrate, and presence of aquatic macrophytes). The substrate was quite variable between sites and likely led to significant variations in our capture efficiency between sites. Parsley et al. (1989) found beach seine capture efficiencies varied with the substrate type, and that capture efficiency is highest over fine substrates and is significantly higher over fine substrates for juvenile chinook. . Substrate size affected our ability to quickly sample the sites. We captured more fish at sites with fewer obstructions to hang the seine up on. Sites with very large substrate (large cobble) were especially difficult without snagging or rolling the net. The presence of milfoil also inhibited our ability to haul the seine at some sites. Weaver et al. (1993) stated that beach seines are selective by species for cool-water fish assemblages; they did not examine selectivity among juvenile salmonid species. We assumed similar efficiencies for all juvenile salmonids. Pierce et al. (1990) showed that littoral habitat complexity (i.e., woody debris and aquatic vegetation) will affect seine efficiency, greater efficiency occurring in aquatic vegetation than in open bottom or woody debris. Sites with coarse substrate or other obstructions may provide greater hiding cover for juvenile salmonids but are also more difficult to seine. Since the lead line of a beach seine can only sweep areas above the substrate, it would be expected that capture efficiencies are lower for fish that hide among rocks when resting or frightened (Parsley et al. 1989). Despite the drawbacks, we used snorkel observations to base most of our decisions on juvenile salmonid habitat relationship upon. Beach seine data were used as a “check” on the composition of snorkel observations.

5.2.2 Snorkel Observations

The accuracy and precision of underwater surveys of salmonids is strongly influenced by biological factors (i.e., behavior of the target species) and by physical conditions (i.e., environmental attributes of the sampling unit). Underwater surveys may be biased by the behavior of different life stages within the same species and by the behavior of various species within the same life stage.

The feasibility of using underwater techniques to assess the presence or absence of fish populations that are fragmented and in low abundance has not been adequately assessed. For most species and life stages, the variability in abundance estimates across a range of habitat conditions is largely unknown. For most species, the sampling effort required to achieve a desired level of accuracy and precision in estimating abundance is likewise, unknown. Thus, our estimates may be biased high or low, but since the data were collected by the same observers and on the same species assemblage (i.e., juvenile salmonids) we feel that they are representative of the true population.

5.2 PREDATORS

Predation is believed to be a major factor influencing the survival of juvenile salmon in Lake Washington, although few data are available. Many of the fish captured in this study could be potential predators of sockeye fry depending upon their size (assuming fish would need to be >69 mm to consume fry) (R. Tabor, USFWS, *pers. comm*.). The major predators on juvenile salmon are presumed to be northern pikeminnow, cutthroat and rainbow trout, yellow perch, *Cottus spp*., smallmouth and largemouth bass (Ricker 1941; Olney 1975; Beauchamp 1987 and 1990). The most important nearshore predator of sockeye fry in Lake Washington was identified as cutthroat trout < 250 mm, while prickly sculpin >125 mm were identified as the most important benthic predator (Lake Washington Sockeye Studies Interim Workshop 2000). Beauchamp et al. (1992) found predation by cutthroat trout to be high on sockeye still residing in littoral areas during the summer. In our study the most abundant potential predators found during the day in littoral areas were yellow perch, cutthroat trout, and rainbow/steelhead trout. At night, the most abundant potential predators were cutthroat trout, rainbow/steelhead trout, and sculpins. We did not delineate sculpin size, however, cursory examination in the field showed that several sculpins >110 mm TL were preying on sockeye fry.

Yellow perch, a non-native predator was present in very low numbers from February through April, but was quite abundant in May and June. Larger yellow perch usually had little or no food in their stomach, as most were ready to spawn. Smallmouth and largemouth bass generally utilize ambush foraging strategies (Hobson 1979). Fayram and Sibley (2000) determined that smallmouth bass in Lake Washington occupied littoral home ranges that radiated 100 to 200 m from their focal point and generally did not extend below 8 m deep. Because of this propensity for ambush foraging and shoreline orientation, bass are expected to benefit from artificial structures placed in the littoral zone. However, in our study no largemouth bass were captured, and only juvenile or YOY smallmouth bass were encountered. A review of the literature found that the majority of known bass predation on juvenile salmonids occurs in the Ship Canal. Smallmouth bass are the primary predator, preying most heavily on chinook fry due to their small size relative to sockeye and coho yearlings.

Hartman and Burgner (1972) report that three-spine stickleback, *Cottus spp*., and smelt may act as “buffers” to predation for sockeye fry. The salmonid fry we captured may be buffered by the numerous prey species that were also moving inshore at this time. Beauchamp et al. (1995) predicted that large cutthroat and rainbow trout are more serious predators of young sockeye in offshore areas because of their greater motility. Eggers (1982) forage model for Lake Washington emphasized predator avoidance as a key feature. While this may be important for stocks with longer freshwater residence times (2-3 years), it may be equally important for Lake Washington salmon juveniles because of the greater abundance and diversity of predators found in this system. Likewise, avian predators may be an important, but largely overlooked, mortality factor for salmonids during their outmigration. However, the magnitude of avian predation on salmonids in Lake Washington is unknown. Ajwani (1956) reported that there has been ongoing predation of salmon smolts at the Ship Canal since the early part of this century. Studies from other systems indicate that consumption rates are substantial (Alexander 1979; Feltham 1990; Suter 1995; Wood 1987; Modde et al. 1996). Because of the presence of predatory birds in Lake Washington and Lake Sammamish, avian predation must be considered among potential threats to juvenile salmonids in this system.

The net loss in complex cover resulting from the replacement of natural shorelines with docks and bulkheads may be critical for juvenile salmonids in Lake Washington. Sustainable predator-prey interactions generally require the existence of prey refugia to prevent the extermination of the prey organism. Numerous studies have reported increased use of complex cover (e.g., aquatic vegetation, woody debris, substrate interstices, and undercut banks) by prey fishes in the presence of predators, and reduced foraging efficiency of predators due to habitat complexity (Wood and Hand 1985; Werner and Hall 1988; Bugert and Bjornn 1991; Tabor and Wurtsbaugh 1991; Persson and Eklov 1995). Simplification of shoreline habitat, thereby reducing the availability of prey refuge-habitat, should be avoided. Predator-prey interactions modify the behavior of both predator and prey species. Prey refugia is essential for the continued existence of vulnerable prey species. Complex habitat features that exclude predators, physically or through risk-aversion, can function as prey refuge. Examples of effective prey refuge may include shallow water, complex substrate, aquatic and emergent vegetation, overhanging terrestrial vegetation, undercut banks, and woody debris. Efforts to restore these functional types of habitat in Lake Washington should be encouraged.

5.3 MILFOIL

Since the introduction of milfoil into Lake Washington, various citizens and agencies have undertaken removal efforts, including application of herbicides. It likely covers less than 360 ha (900 ac) of habitat at this time. Milfoil was present throughout all of our survey sites. It appeared to achieve its maximum annual biomass during the months of July through September. During our beach seine surveys conducted from April through

June we did not encounter large or dense beds. Milfoil was observed primarily between the depths of 2-6 m.

One concern is that milfoil, especially when very dense, may reduce the quality and quantity of habitat available for juvenile salmon while enhancing habitat for species such as juvenile pikeminnow and exotic yellow perch that are attracted to milfoil. Durocher et al. (1984) indicated that largemouth bass are enhanced by the presence of submerged aquatic vegetation; however no studies have been conducted in Lake Washington to determine if particular species utilize beds of milfoil or when this occurs. It is possible that bass and perch and other predators may rest in beds of milfoil. Increased abundance of northern squawfish juveniles has been associated with growth of milfoil (Gregory and Levings 1993).

Yet another concern of milfoil is that juvenile salmonids may alter their migration path to avoid milfoil. Milfoil beds often parallel the shoreline. This study has not produced enough data relative to the occurrence of milfoil to determine whether salmonid fry avoid or are present in areas of milfoil infestation. The density of milfoil observed in our survey sites did not appear sufficient to significantly interfere with migrating salmon due to the fact that the top of most milfoil was 1 to 2 meters below the surface.

5.4 SPAWNING

Little is known regarding spawning site selection criteria for populations of beach spawning salmonids, such as sockeye salmon. Studies indicate that beach spawning salmonids may select spawning sites in shallow water near shore (Curtis and Fraser 1948; Emmet and Convey 1992; Gipson and Hubert 1993). Subsequently, spawning densities are highest near shore (Kerns and Donaldson 1968; Quinn et al. 1996), although deep water spawning does occur in Lake Washington (Hassemer and Reiman 1981; Beauchamp et al. 1992). Where groundwater upwelling is absent or negligible, water flow at beach spawning sites is probably attributable to wind induced currents and seiches. Previous research has demonstrated that salmonid incubation survival correlates positively with intragravel water flow and the delivery rate of dissolved oxygen, both are functions of gravel size or permeability (Wickett 1954; Coble 1961; McNeil and Ahnell 1964, Shumway et al. 1964).

5.5 RECOMMENDATIONS

In this study the Corps found the highest use of shoreline to have occurred along sections of shoreline that contained overhead cover, cobble substrate, shallow-sloping bank and nearshore contours, and banks without armoring. Unfortunately the complex shoreline once present along Seward Park, has been replaced with structurally simple bank protection. The loss of natural shoreline around Seward Park has reduced complex shoreline features such as overhanging and emergent vegetation, woody debris (especially fallen trees with branches and/or rootwads intact), and gravel/cobble beaches. Currently, only 18% of the Bailey Peninsula shoreline has overhanging vegetation, which is in stark contrast to its historical condition. Evermann and Meek (1897) noted in 1896 that "the shore of Lake Washington is not well adapted to collecting with a seine" due to the abundant submerged woody debris, and dense underbrush, small trees, and tule (hardstem bulrush) that fringed the shoreline. The loss of complex habitat features (i.e., woody debris, overhanging vegetation, emergent vegetation), and shallow-water habitat from Seward Park has most likely reduced the availability of refuge habitat and forage for juvenile salmonids as well as reduced allocthonous input of detritus and terrestrial insects. Due to these reasons the Corps recommends rehabilitating and preventing future losses of these habitats as a priority for the City in its management of Seward Park lakeshore.

The southeast shoreline of Seward Park contains a fairly significant length of a concrete bulkhead. The Corps recommends the removal of this bulkhead and the incorporation of several shoreline rehabilitation features (i.e., native emergent and riparian plant species, shallow sloping beach, woody debris) in combination with emergent vegetation for wave energy attenuation. Literature indicates that bulkheads may negatively affect salmonids in several ways. Bulkheads have been shown to eliminate littoral habitat and complex habitat features that may function as critical prey refugia for juvenile salmonids. Collins et al. (1995) identified shallow water as critical for foraging, refuge, and migration of small fish (<100 mm). Schlosser (1987) found shallow water especially important in the absence of complex habitat features such as woody debris or submerged vegetation. Bulkheads have also been shown to reduce the diversity and abundance of all fish species except smallmouth bass in north-temperate lakes. Lange (1999) found that bank stabilization (i.e., various forms of erosion control structures referred to as "bulkheads") was negatively correlated to fish abundance and species richness at all spatial scales investigated in Lake Simcoe, Ontario.

In several areas along the shoreline, quarry spalls have washed out into the nearshore habitat creating an "armored" substrate. Substrate is important because it has potential use as cover, spawning, and feeding habitat for juvenile salmonids. The quarry spalls lack any habitat quality for salmon but may provide good ambush habitat for several species of sculpins that prey upon juvenile salmon. Spalding (1998) indicated a change in sediment composition could cause a change in meiofauna density and that bulkheads could adversely affect benthic organisms in freshwater lakes. Another potential problem of the quarry spalls may be that it eliminates any potential sockeye spawning since it is too large to use for spawning. To alleviate this problem, the Corps recommends that a gravel layer be placed over the areas that have become armored by quarry spalls (see Table 12 for the recommended size gradation).

Table 12. Recommended gravel size distribution for areas armored by quarry spalls along Seward Park, King County, Washington (Allen and Meekin 1973).

Sieve Size (mm)	**Percent Passing by Weight**
101.6	100
63.5	80-90
50.8	70-85
38.1	55-70
25.4	25-50
19	0-20
12.7	0

5.6 RECOMMENDATIONS FOR FUTURE STUDIES

Studies should be directed at determining the predator population response to shorezone alterations and structures to determine if these alterations enhance predator abundance or simply concentrate the population in predictable areas. If predator populations are limited by factors other than structure availability, placing additional structures may not increase their abundance.

Determine the spatial and temporal correlation between artificial structure placement, juvenile salmonid abundance, and predators. A replicated before and after, treatment and control experiment utilizing different habitat complexities may indicate a preference of juvenile salmonids for certain conditions. At the minimum, juvenile salmonid surveys should be conducted for another season (January through December) and two season after construction is completed. Sockeye beach spawning surveys should also be maintained over the same time frame.

6. ANALYSIS OF DESIGN AND ESTIMATES OF COST

6.1 LAKE LEVEL

The level of Lake Washington is regulated by the Corps. The maximum allowable Lake Level was established by Congress in 1910 at an elevation of 6.7 m (22 ft) above the Lake Datum. The Corps regulates the level of Lakes Washington and Union through its operation of spillway gates at the Locks. Each winter the lake level is lowered about 0.6 m (2 ft) and held at an elevation of 6.1 m (20 ft) to provide flood control for Seattle and to reduce potential shoreline damage from winter storms. In the spring the level is raised slightly less than 0.6 m (2 ft) for the benefit of fish and summer recreation. The Corps usually lowers the lake between June and November and then raises the level between February and May (Figures 19 and 20).

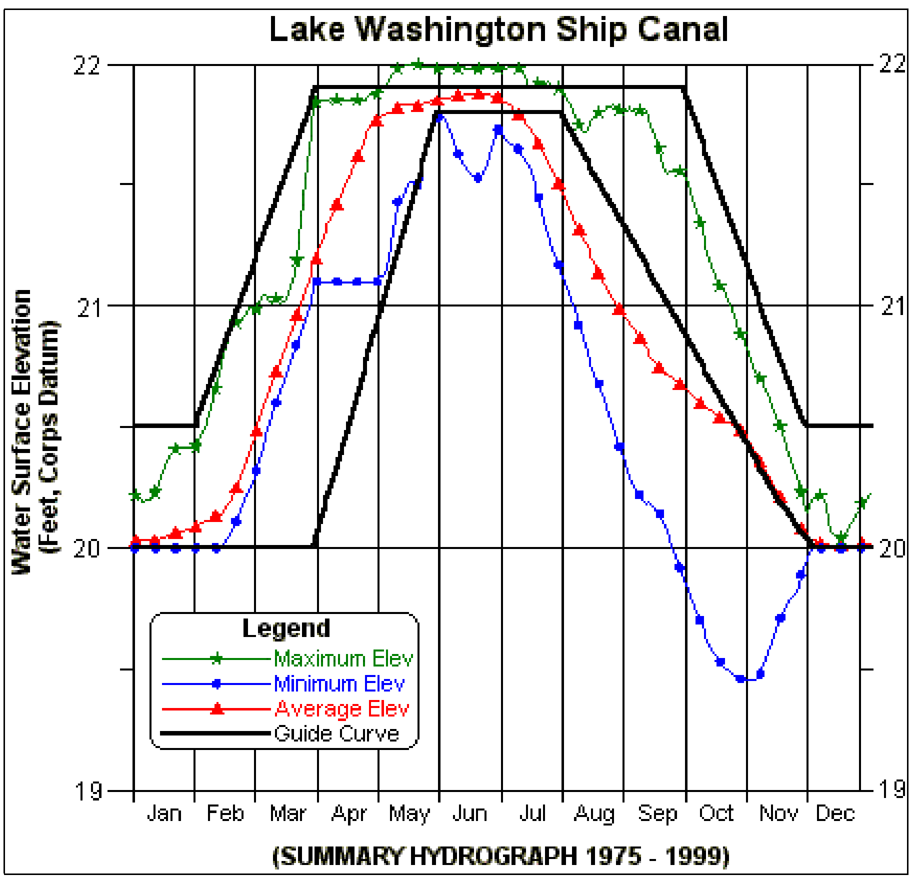


Figure 19. Lake Washington Ship Canal hydrograph, King County, Washington, 1975-1999.

Relation Between Various Datum Planes

Datum Plane	MLLW	NGVD	NAVD88	COE	CITY
Highest Estimated Tide					
Mean Higher High Water	11.35	5.25	8.83	12.05	-.88
Mean High Water	10.49	4.39	7.97	11.19	-1.74
Mean (Half) Tide Level	6.66	0.56	4.14	7.36	-5.57
NGVD	6.10	0.00	3.58	6.80	-6.13
Mean Low Water	2.83	-3.27	0.31	3.53	-9.40
Mean Lower Low Water	0.00	-6.10	-2.52	0.70	-12.23
Lowest Estimated Tide					

Record Levels (MLLW)	
Highest Observed Tide	
Date	12/15/77
Lowest Observed Tide	-4.60
Date	6/20/51
Period of Record	
Epoch	1960 - 1978
Index Gage	

Local Area Map

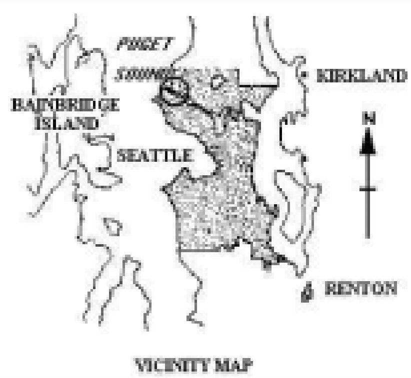


Figure 20. Datum layers for the Hiram M. Chittenden Locks, King County, Washington.

6.1.1 Prevailing Winds

Topography plays a large role in influencing the surface wind pattern of the Puget Sound region. In the summer, winds are generally light, and from the north. In October, the surface wind becomes primarily southerly and remains in this direction throughout the winter months, with the exception of occasional strong northerly winds generated by arctic cold fronts. The average yearly wind diagram for Seattle-Tacoma Airport, and velocity-duration curves used for Lake Washington wave analysis are presented in Figures 21 and 22.

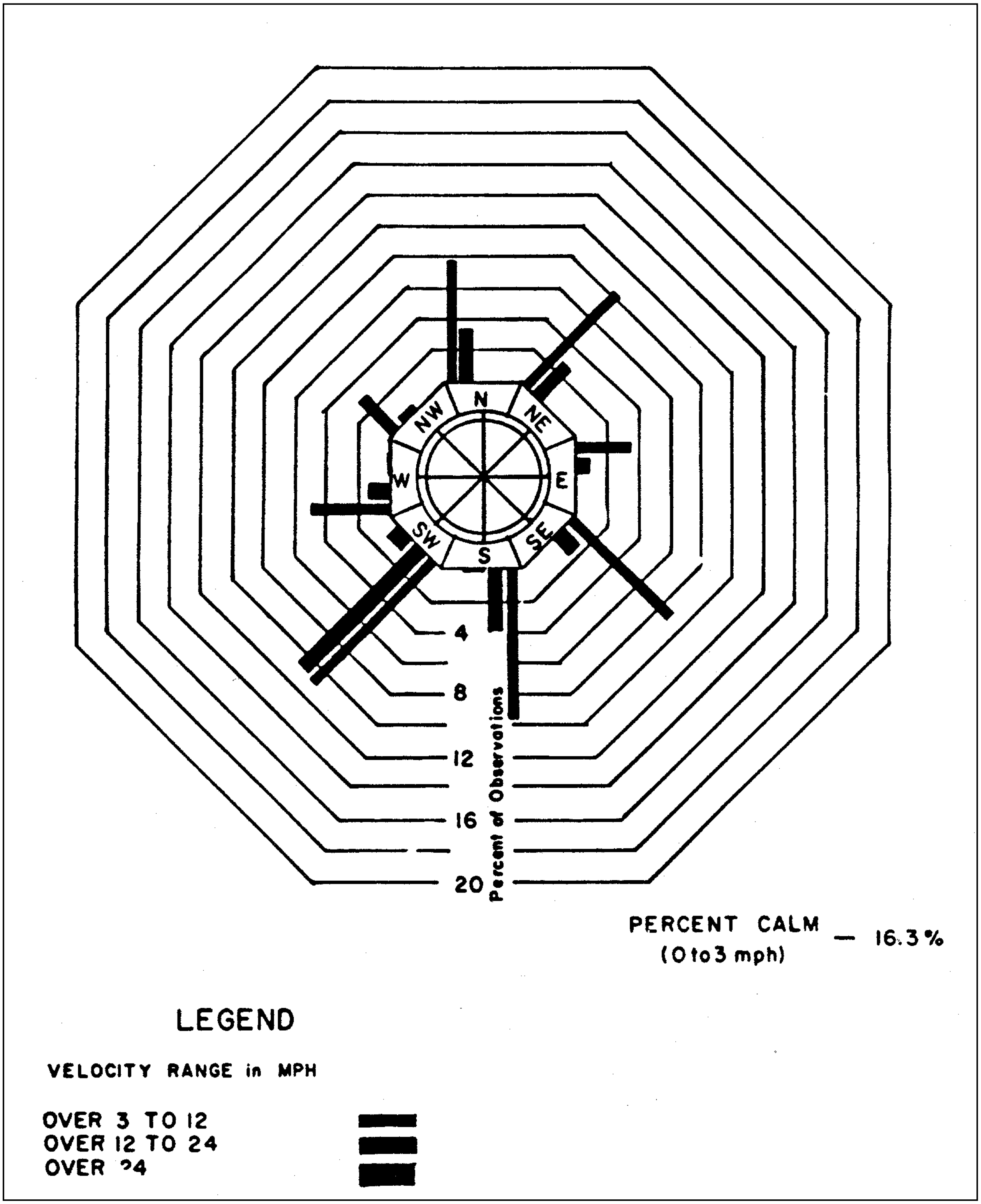


Figure 21. Wind rose diagram for Sea-Tac International Airport, Seattle, Washington, 1949-1969.

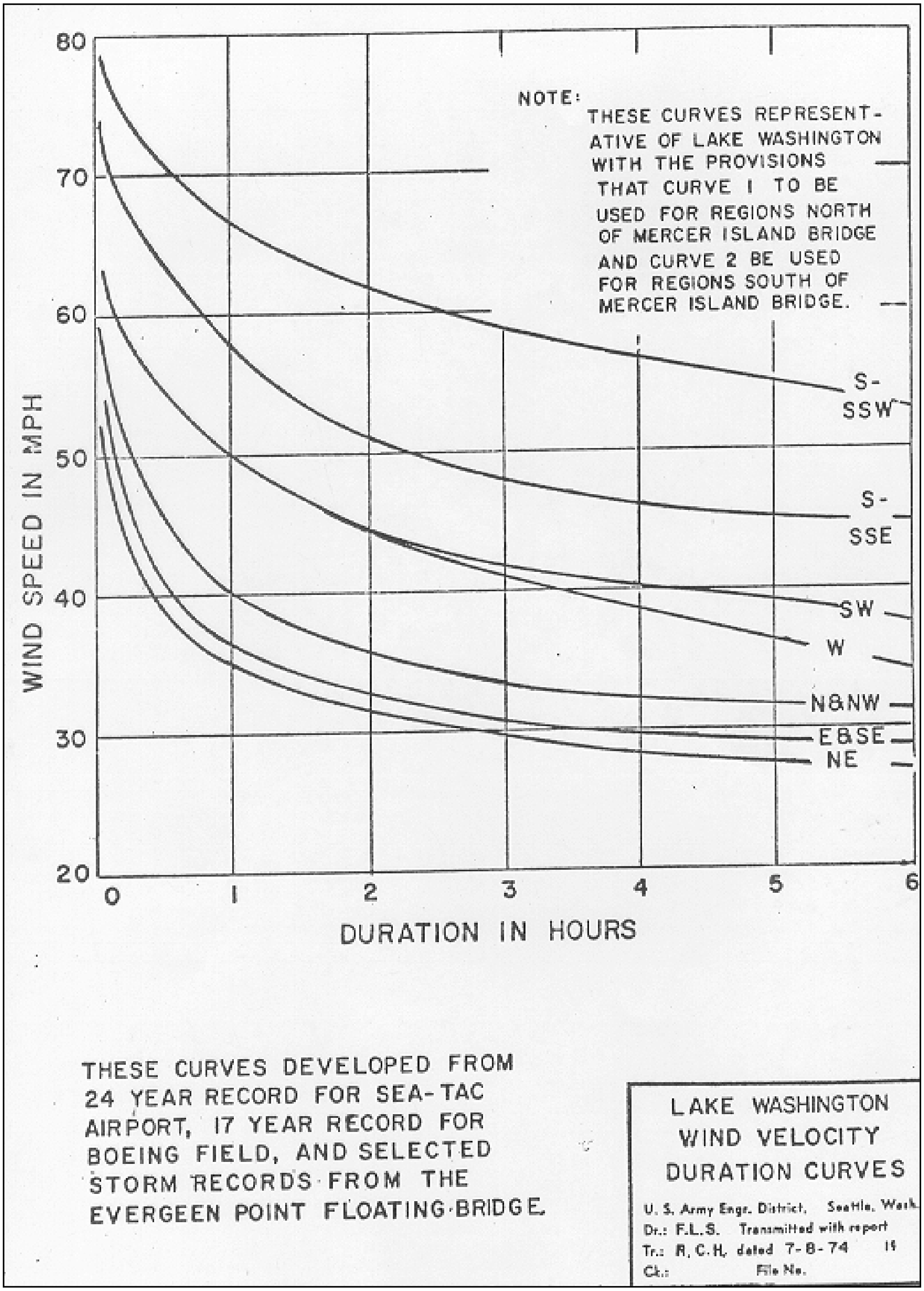


Figure 22. Lake Washington wind velocity duration curves, King County, Washington.

6.1.2 Wind Generated Waves

The Seward Park shoreline is exposed to wind waves from the south, east, and north. The proposed erosion control measures are exposed primarily to waves from the south and north. The Wind Speed Adjustment and Wave Growth application in ACES version 1.07f was used to calculate wave heights and periods for waves that approach from the major fetch directions. For the 2.5 statute-mile fetch to the south, a 67 mph wind with a 1 hr duration was calculated to generate a fetch-limited significant wave height (H_{mo}) of 4 ft with a period (T_p) of 3.7 sec. Similarly, a 48 mph wind from the north generates a somewhat smaller fetch limited significant wave height (H_{mo}) of 2.7 ft with a period (T_p) of 3.1 sec (Figures 23 and 24).

6.1.3 Beach Profiles

The Seward Park Shoreline was broken into six reaches based on wave exposure Figure 25). Representative transects were surveyed for each reach by the Corps of Engineers in October 1999 (Figure 26). These transects indicate that the near shore bottom has a relatively gentle (1:7 to 1:12) slope at the north and south ends of the peninsula (Reach 1 and 3) but has an exceptionally steep slope (>1:4), along the east and west shorelines. This survey information is consistent with NOAA navigation charts of the area (Figure 27). On the southern shore, diver observations indicate that the bottom is primarily sand, turning to gravel and cobble along the eastern shoreline. On the north shore, the natural bottom material appears to be sand, covered by angular (manufactured) rock, primarily near groins placed at the east and west corners. The bottom along the western shore is composed of sand and gravel, both natural and placed. As a result of previous shore protection efforts, the bottom in some areas along the east shoreline is covered by a layer of small quarry spalls.

The upper beach (stations +21' - +25') is a steep bank, probably created by the "cut and fill" technique used when the walkway around the park was constructed. Essentially all the this bank is "hardened" with various types of materials, including large rip rap, small rip rap, gravel, broken concrete, and concrete slabs. With minor exceptions, these measures appear to be effective in protecting the upper bank from erosion.

6.1.4 Littoral Transportation

The net transport of any available littoral material would be from the south to the north due to a prevailing wind from the south. The shallow beach composed of sand at the south end of the park indicates that littoral material accretion has occurred at the south end of the park. However, the littoral processes along the Lake Washington shoreline have been modified extensively by the construction of bulkheads and piers along most of the lake shoreline and presently, the Bailey Peninsula probably receives only a minor amount of littoral material from the south. Any material that erodes from park shorelines is probably carried northward and lost permanently in deep water at the northern tip of the park. For this reason, the peninsula has always acted as an effective barrier to the movement material along the lake shoreline.

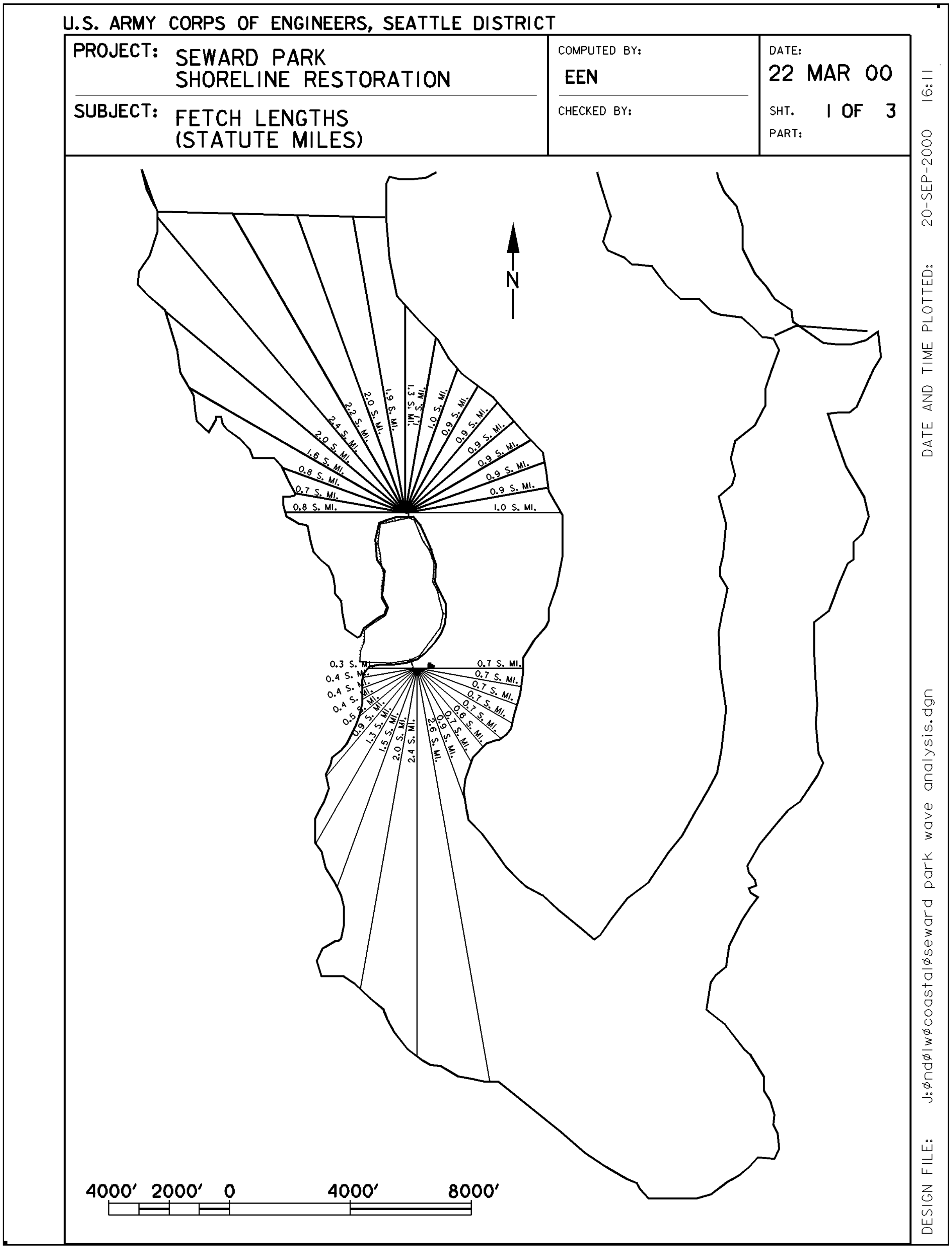
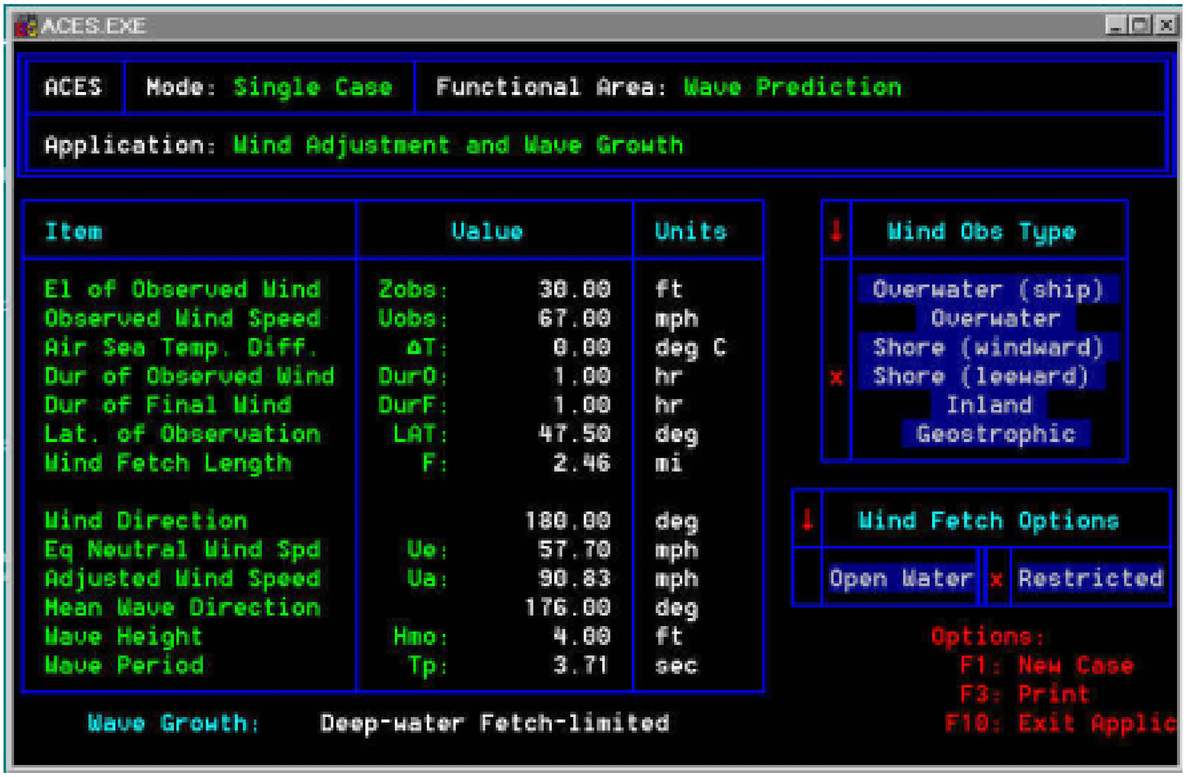


Figure 23. Fetch lengths in statute miles for Seward Park, King County, Washington.



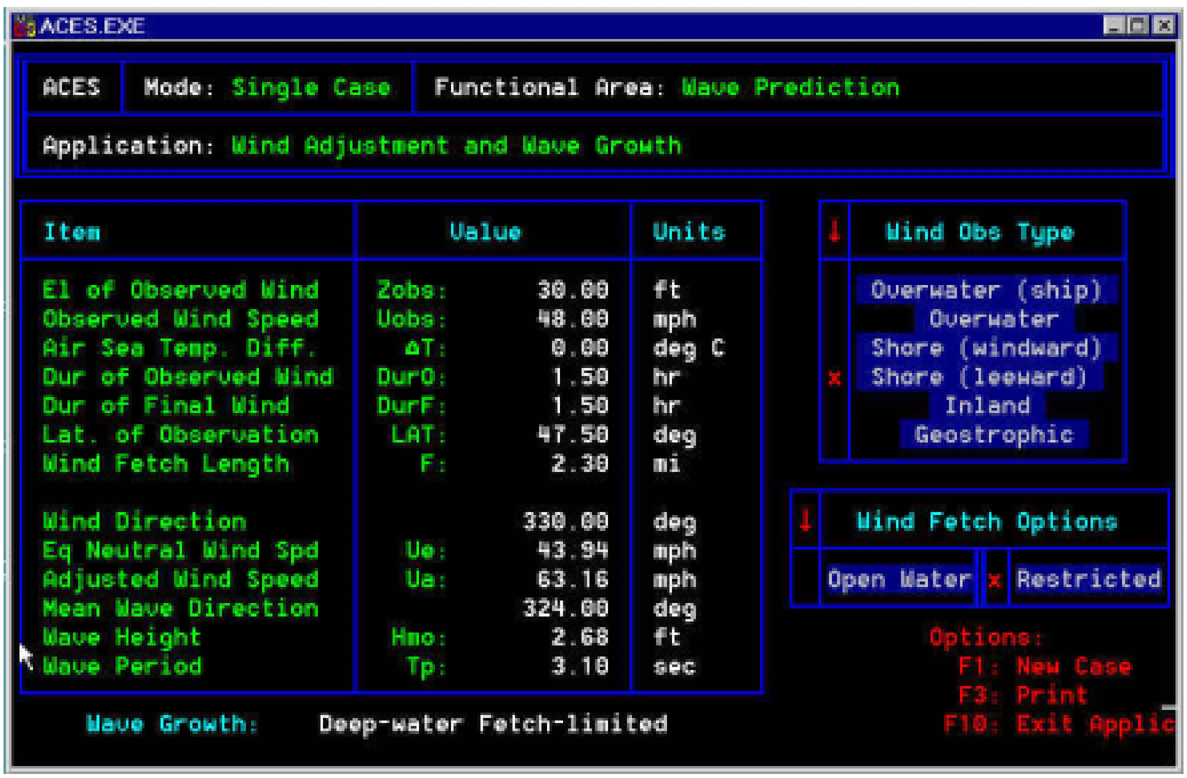


Figure 24. Wind adjustment and wave action output from Wind Speed Adjustment and Wave Growth 1.07f, USACE, Seattle Washington.

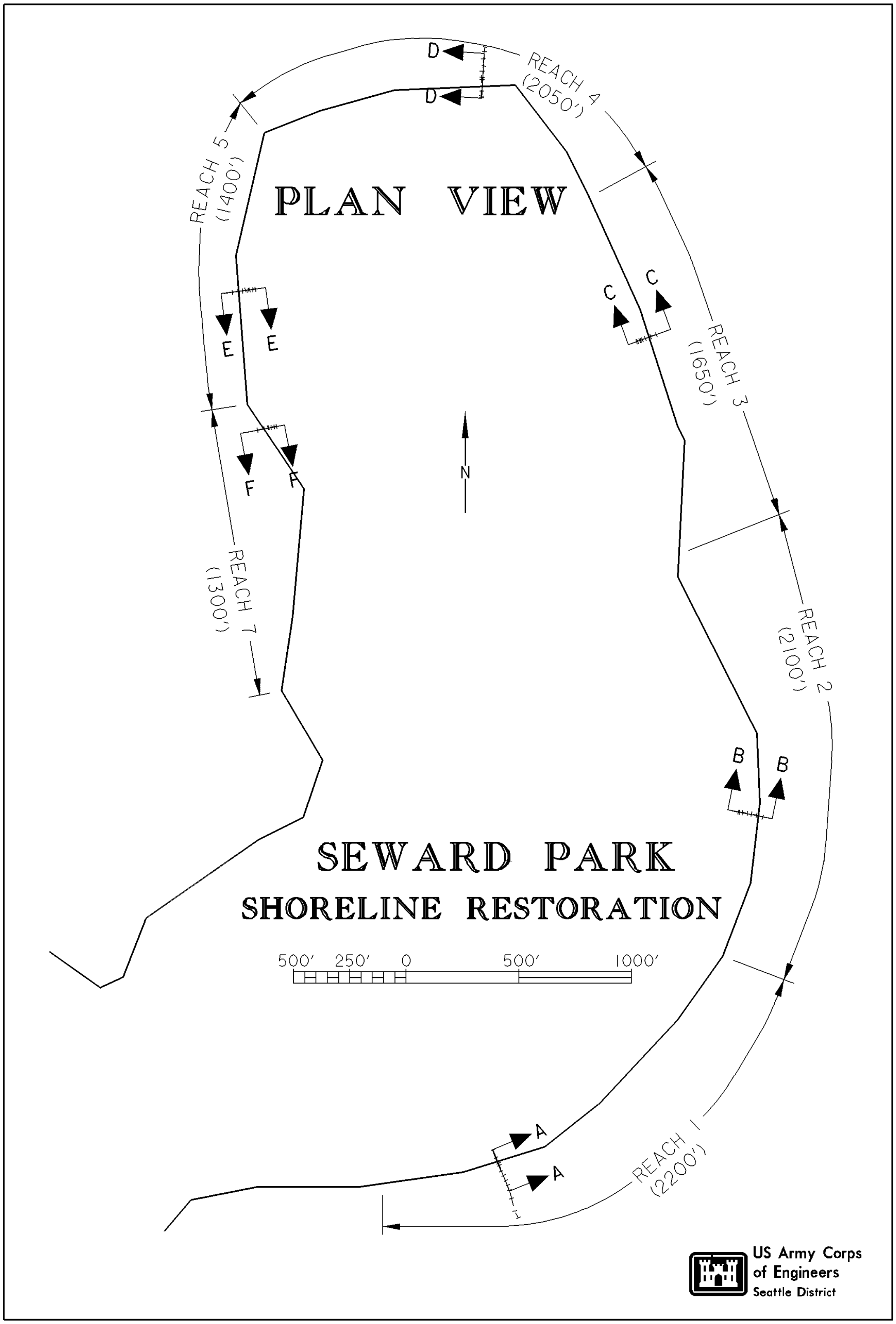


Figure 25. Seward Park Rehabilitation Site, King County, Washington, 1999-2000.

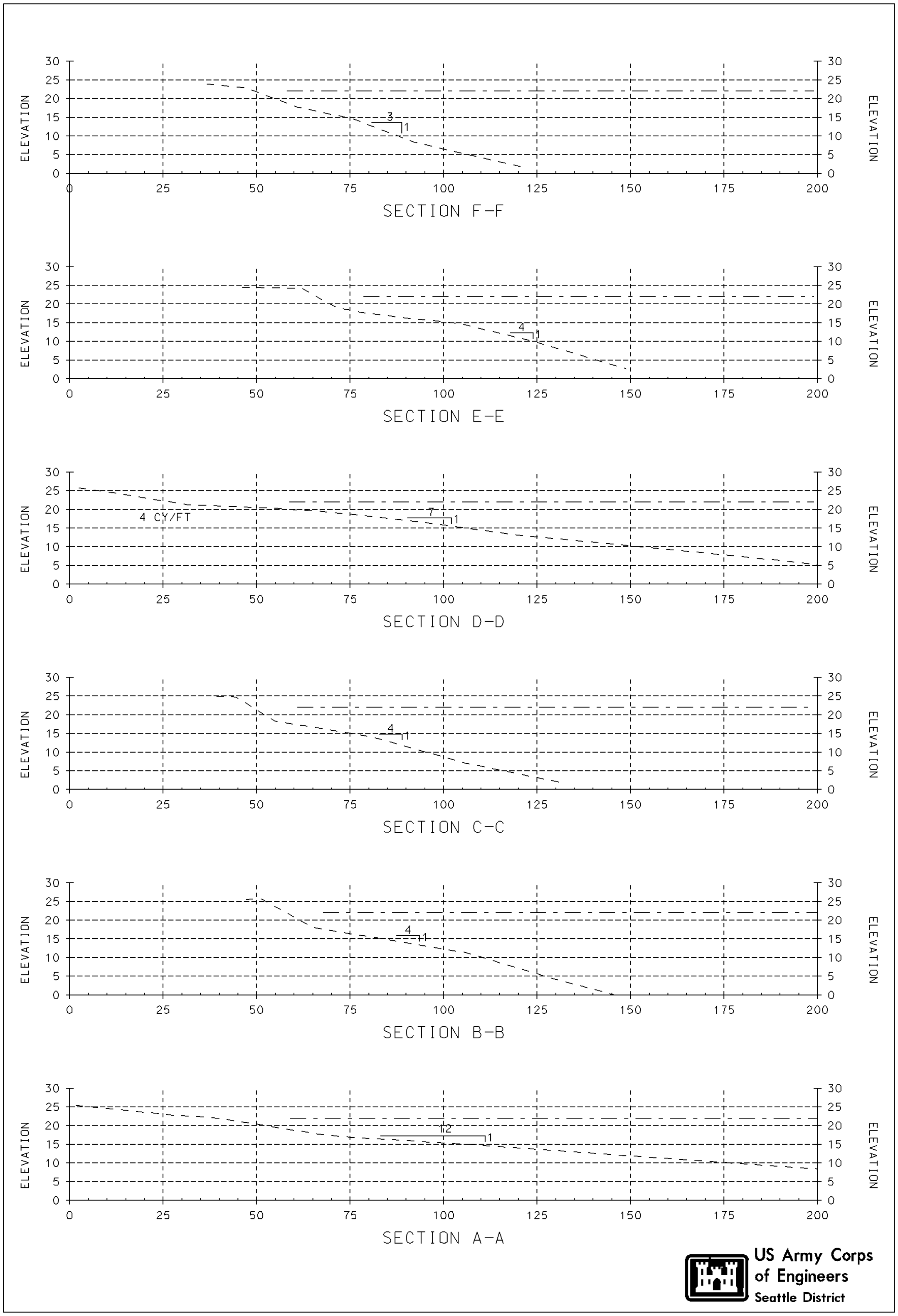


Figure 26. Transect data collected at six sites along Seward Park, King County, Washington.

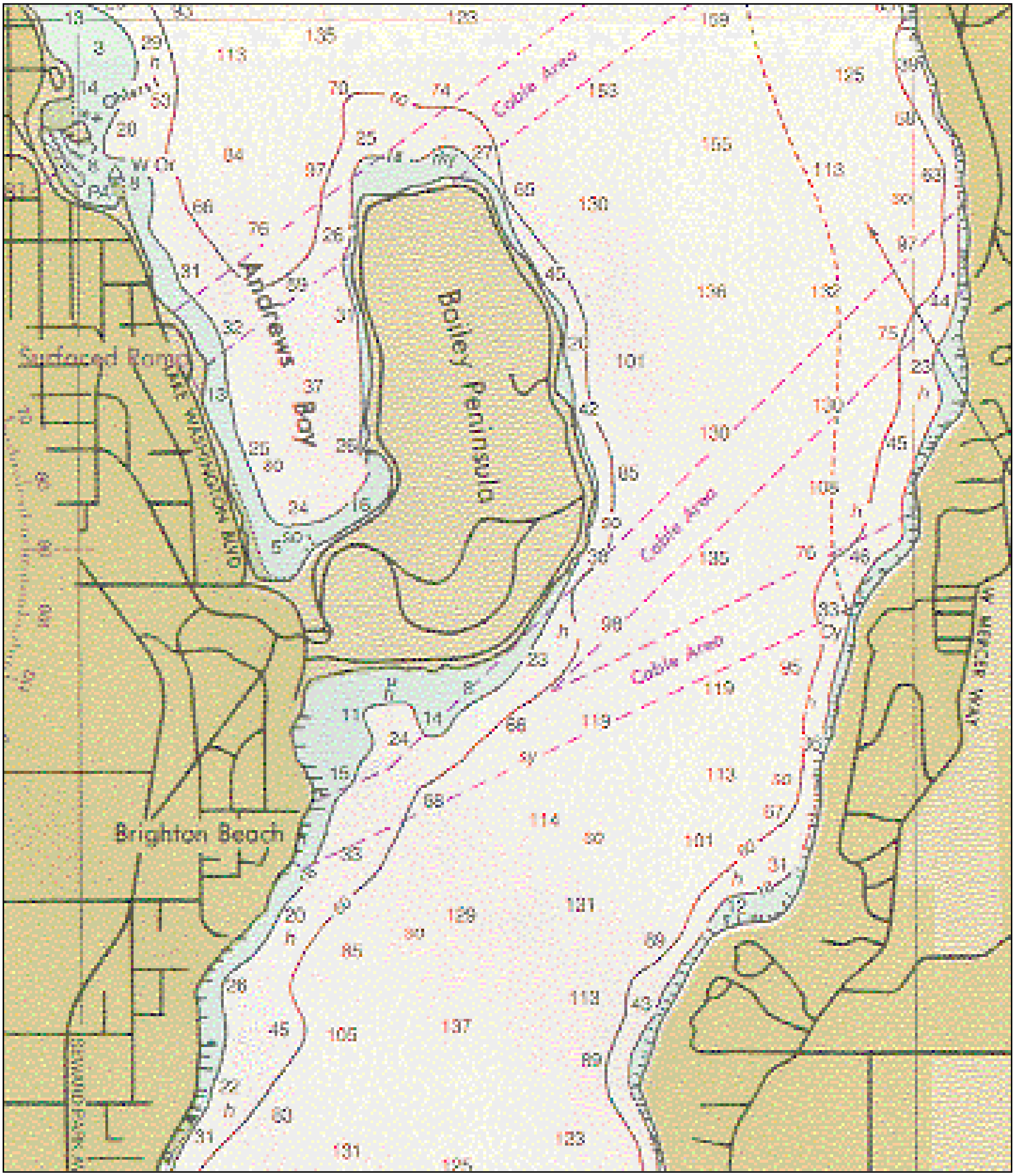


Figure 27. Bathymetric map of Lake Washington near Seward Park, King County, Washington.

7. HABITAT REHABILITATION - DESIGN FEATURES

7.1 HABITAT REHABILITATION DESIGN

In determining the shoreline rehabilitation design, major considerations were those related to providing safe passage for migrating and foraging salmon fingerlings. Factors considered in the location and type of rehabilitation measures included: existing bathymetry, direction of wave approach, fish migration, and maximizing near shore and bank overhanging habitat. The exceptionally steep near shore slopes combined with the effects of wave action limit the options for creating long reaches of shallow water habitat on the east and west shorelines. The proximity of the shoreline walkway restricts the opportunities for modifying the uplands to create shallow water habitat, but the relatively steep bank may allow the planting of vegetation that will overhang the near shore shallow water. The proposed project includes three elements, see figure 28. The first element includes rehabilitating the near shore area by placing a 1-foot-layer of sand, gravel, and cobbles over the selected portions of the western and northern shoreline that are now covered with angular. Also, additional shoreline complexity would be created by placing small woody debris at a number of locations. The second element involves re-vegetating areas in and immediately above the existing bank along the west and north shorelines. This vegetation is intended to replace overhanging vegetation which probably occupied much of the pre-development shoreline. The third element is a shallow near shore area that would be created by excavating upland material along a 500-foot-long section of the southeast shoreline and by allowing natural erosion processes to shape a portion of the adjacent shoreline.

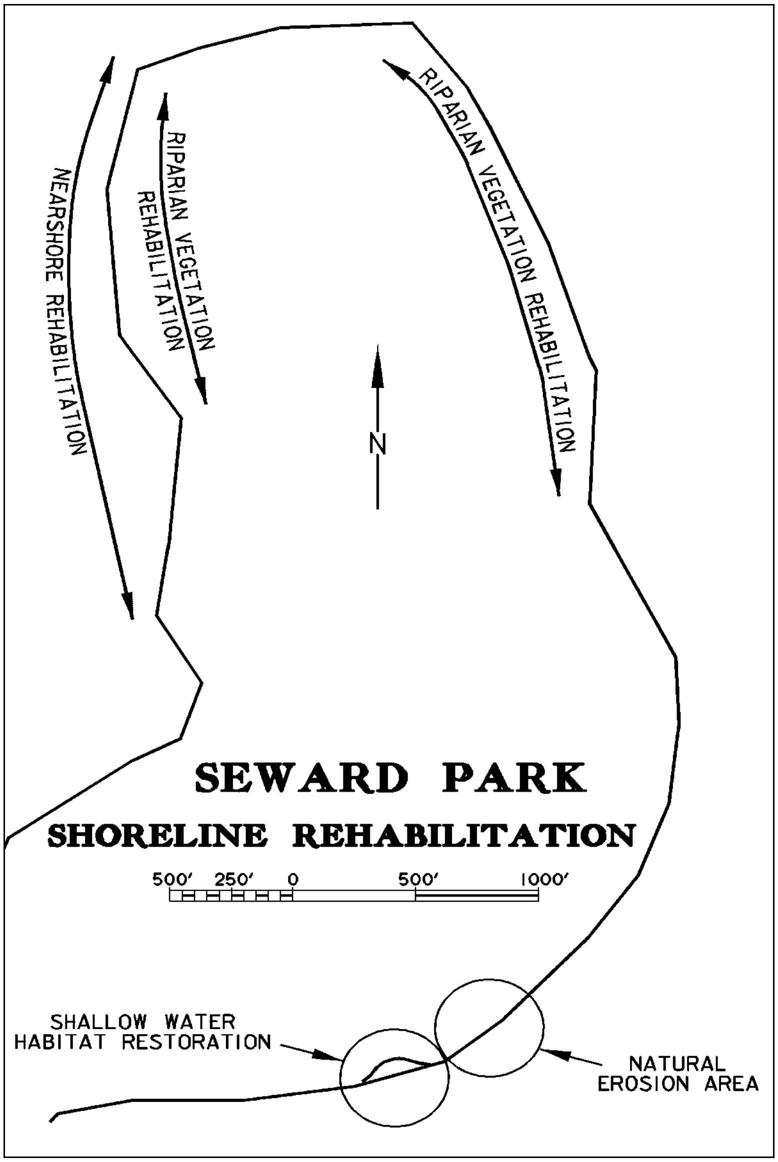


Figure 28. Conceptual diagram of the habitat rehabilitation design for Seward Park, King County, Washington.

7.2 ELEMENT 1 - NEAR-SHORE REHABILITATION

This rehabilitation measure consists of placing a 1-foot-thick layer of gravel and cobbles over selected portions of the near shore bottom to cover angular quarry stone left over from previous erosion control projects. Material would be placed from a barge and would extend from the shore for a distance of 50 feet off shore. Areas proposed for placement include approximately 1000 lineal feet along the west shore, 250 lineal feet at the northwest and northeast corners of the peninsula, and 500 lineal feet along the east shore. The required quantity of sand, gravel, and cobbles is estimated at 4000 cy or approximately 7,000 tons. The west shore site would be divided into two areas, one for fine grained, sandy material and one coarse gravel and cobbles. These areas could be monitored to assess the habitat value of each material. One placement method that has been used successfully in the past is to offload material from a barge by conveyor. This placement method allows material to be placed accurately and efficiently (Figure 29).

Figure 29. Barge offloading substrate material by conveyor belt as proposed as an alternative for use in the Seward Park Rehabilitation Project, King County, Washington.

Additional near shore rehabilitation work would include partially burying small woody debris at selected locations around the peninsula shoreline. Each log would be secured in place at an elevation of about 20' with several large boulders, see figure (Figure 30).

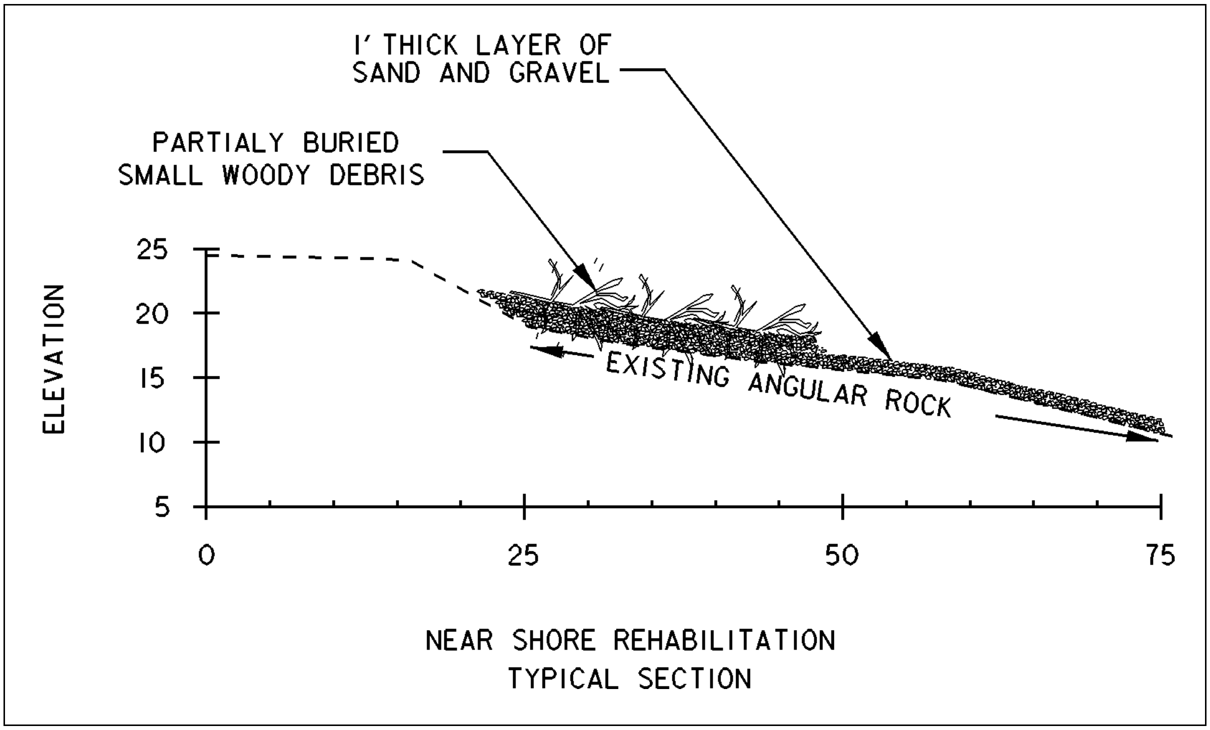


Figure 30. Conceptual design of nearshore Rehabilitation in Seward Park, King County, Washington.

7.3 ELEMENT 2 - UPLAND PLANTINGS

Numerous opportunities appear to be available to improve the quantity and quality of riparian vegetation along many sections to the existing shoreline. The west and north shores would benefit from large overhanging vegetation, such as willows. At a number of locations, 10-31 cm (4-12 in) rip-rap, placed on a 1:1.5 slope has been used to prevent sloughing and erosion of the 0.9- 1.2 m (3-4 ft) high bank that extends from the high lake level (6.4 m; 21 ft) to the walkway elevation (7.6 m; 25ft). While the rip rap is essentially "in the dry" (except during storm conditions), some Rehabilitation potential may be realized by planting vegetation that can grow in the interstitial spaces, eventually covering the rip rap and overhang the nearshore beach. This would be accomplished by placing topsoil over the existing rock and then planting vegetation such as willows. The cost of Element #2 is estimated at $100,000.

Picture 1. Puyallup River April 1998 WCC crew installing willow stakes into lower slope of riprap

Picture 2. Puyallup River November 2000. Two years of willow and dogwood growth.

7.4 ELEMENT 3 - SHALLOW WATER HABITAT

A shallow water habitat area is proposed to be constructed on the southwest shore of the park by excavating approximately 1,900 m^3 (2,500 yd^3) of upland material and relocating existing concrete planks landward to form a small embayment in the shoreline (Figure 31). The embayment would extend up to 15 m (50 ft) into the existing shore for a distance of approximately 76 m (250 ft). The existing ground elevation of 7.6 m (+25 ft) would be lowered by an average of about 2.1-5.8 m (7-19 ft), or about 0.6 m (2 ft) below the summer lake level. This would create approximately 0.1 ha (0.25 ac) of littoral habitat with water depths of between 0.3-0.9 m (1-3 ft). The existing concrete plank bulkhead along this portion of the shoreline would be removed and reused to act as a 0.9-m (3 ft) -high retaining wall (el. 6.7 m;+22 ft to 7.6 m; +25 ft) around the perimeter of the embayment. Constructing the shallow water habitat, assuming reuse of the concrete planks is estimated to cost approximately $300,000.

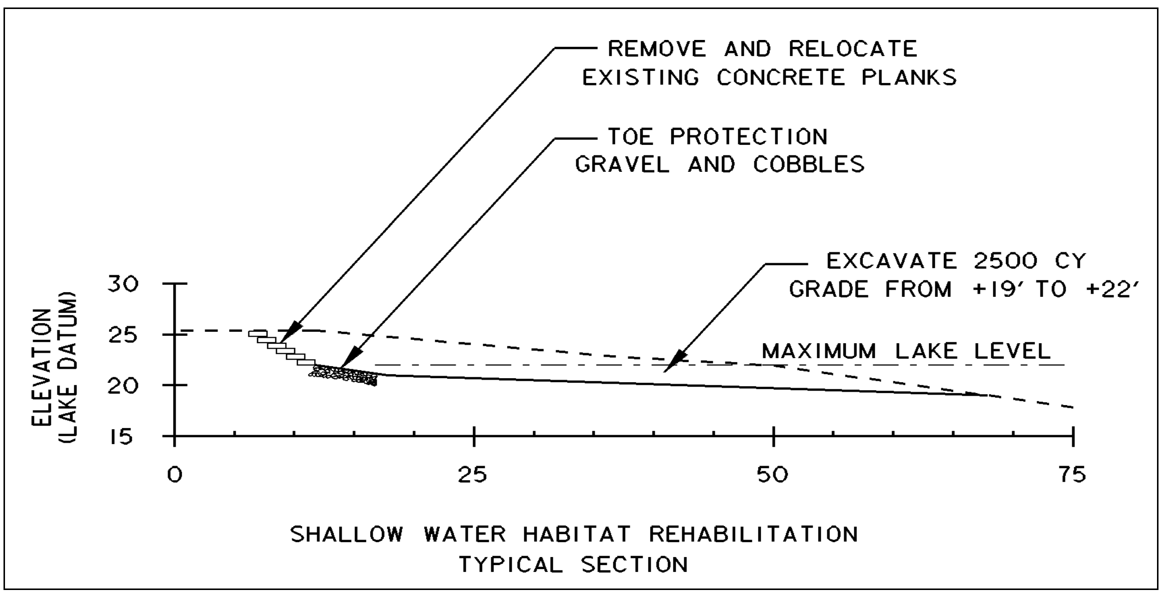


Figure 31. Conceptual diagram of the design of shallow water habitat for Seward Prak, King County, Washington.

7.5 PROJECT EFFECTS

The Seward Park Peninsula is isolated from what little long-shore transport of sediment that may be taking place along the shore of Lake Washington. Construction of the proposed shore Rehabilitation measures, or any other design for that matter, will have no effect on the sediment transport along adjacent beaches. After some resorting and self armoring, the gravel and cobble material proposed for covering the areas of existing angular rock should become resistant to erosion by wave action. This gradation of material has proven to be remarkably stable under much harsher conditions at the City's Lincoln Park.

7.6 DESIGN AND CONSTRUCTION SCHEDULE

The design and construction schedule of Seward Park Federal Rehabilitation Project is shown below. The schedule assumes project authorization and adequate Congressional funding. The construction period will extend from September 15 through March 15. In-water construction will not be conducted within the migration window of juvenile salmonids.

Submit Final Detailed Project Report	NOV 2001
Initiate Plans and Specifications	JAN 2002
Advertise Construction	JUL 2002
Award Contract	SEP 2002
Notice to Proceed	SEP 2002
Complete Basic Features	JAN 2002

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